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Report of the International Ice Patrol in the North Atlantic

International
Ice Patrol

1986 Season
Bulletin No. 72
CG-188-41

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Bulletin No. 72

REPORT OF THE INTERNATIONAL ICE PATROL SERVICES IN THE NORTH ATLANTIC OCEAN

Season of 1986

CG-188-41

FOREWORD

Forwarded herewith is bulletin No. 72 of the International Ice Patrol describing the Patrol's services, ice observations and conditions during the 1986 season.

CLYDE E. ROBBINS
Chief, Office of Operations

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International Ice Patrol 1986 Annual Report

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Introduction

This is the 72[nd] annual report of the International Ice Patrol Service in the North Atlantic. It contains information on ice conditions and Ice Patrol operations for 1986. The U.S. Coast Guard conducts the International Ice Patrol Service in the North Atlantic under the provisions of U.S. Code, Title 46, Sections 738, 738a through 738d; and the International Convention for the Safety of Life at Sea (SOLAS), 1974, regulations 5-8. This service was initiated shortly after the sinking of the RMS TITANIC on April 15, 1912.

Commander, International Ice Patrol, under Commander, Coast Guard Atlantic Area, directed the International Ice Patrol from offices located at Groton, Connecticut. International Ice Patrol analyzes ice and environmental data, prepares the daily ice bulletins and facsimile charts, and replies to any requests for special ice information. It also controls the aerial Ice Reconnaissance Detachment and any surface patrol cutters when assigned, both of which patrol the southeastern, southern, and southwestern limits of the Grand Banks of Newfoundland for icebergs. The International Ice Patrol makes twice-daily radio broadcasts to warn mariners of the limits of iceberg distribution.

Vice Admiral P.A. Yost was Commander, Atlantic Area from the start of the 1986 season, March 27. Vice Admiral D.C. Thompson became Commander, Atlantic Area on May 27, 1986. Commander Norman C. Edwards, Jr., U.S. Coast Guard, was Commander, International Ice Patrol during the Ice Patrol season.

Summary of Operations, 1986

During the 1986 Ice Patrol season, from March 27 to July 3, 1986, the International Ice Patrol (IIP), a unit of the U.S. Coast Guard, conducted the International Ice Patrol Service, which has been provided annually since the sinking of the RMS TITANIC on April 15, 1912. During past years, Coast Guard ships and/or aircraft have patrolled the shipping lanes off Newfoundland within the area delineated by 40°N - 52°N, 39°W - 57°W, detecting icebergs and warning mariners of these hazards. During the 1986 Ice Patrol season, Coast Guard HC-130 aircraft flew 45 ice reconnaissance sorties, logging over 294 flight hours. The AN/APS-135 Side-Looking Airborne Radar (SLAR), which was introduced into Ice Patrol duty during the 1983 season, again proved to be an excellent all-weather tool for the detection of both icebergs and sea ice, providing 26.1 percent of all 1986 sightings.

Deployments were made February 1- 5 and March 11-20 to determine the pre-season iceberg distribution. Based on the latter trip, regular deployments started on March 25 with the 1986 season opening on March 27. From that date until July 2, 1986, an aerial Ice Reconnaissance Detachment (ICERECDET) operated from Gander, Newfoundland one week out of every two. The season officially closed on July 3, 1986.

During the 1986 ice year, an estimated 204 icebergs drifted south of 48°N latitude. Table 1 shows monthly estimates of the number of icebergs that crossed 48°N.

Six satellite-tracked oceanographic drifters were deployed to provide operational data for IIP's iceberg drift model. The drift data from these buoys are discussed in Appendix B.

No U. S. Coast Guard cutters were deployed to act as surface patrol vessels this year. The USCGC EVERGREEN was deployed to conduct oceanographic research for the Ice Patrol during the period April 22 through May 22. In 1986, research efforts were directed toward studying ocean frontal features associated with a warm core eddy between the Grand Bank and the North Atlantic Current. SLAR was used to map the surface roughness gradients across frontal boundaries. The study area was re-mapped weekly during the month of May. Based on the initial SLAR survey, a series of hydrographic transects were made of the eddy, and satellite-tracked drifting buoys were deployed in the area. The results of this study are presented in Appendix C.

Table 1. Icebergs South of 48° North *The three periods shown are ship reconnaissance (1900-45), aircraft visual reconnaissance (1946-82) and SLAR reconnaissance (1983-85)*

	Avg 1900-45	Avg 1946-82	Avg 1983-85	1986
OCT	2	0	1	0
NOV	2	0	4	0
DEC	2	0	3	0
JAN	3	7	4	0
FEB	10	8	74	3
MAR	46	32	118	40
APR	105	85	500	60
MAY	154	81	384	59
JUN	77	50	214	24
JUL	26	13	178	18
AUG	9	3	45	0
SEP	5	0	14	0
Total	441	279	1539	204

Table 2. Source of International Ice Patrol Iceberg Reports by Size

Sighting Source	Growler	Small	Medium	Large	Radar Target	Total	Percent of Total
Coast Guard SLAR	44	101	37	13	10	205	26.1
Coast Guard Visual	7	56	44	21	0	128	16.3
CanadianSLAR	1	16	14	1	65	97	12.4
Canadian Visual	0	20	16	1	0	37	4.7
Commercial Radar	8	10	10	1	31	60	7.6
Commercial Visual	5	33	112	26	0	176	22.4
Offshore Industry	0	3	0	1	2	6	0.8
Lighthouse/Shore	0	0	0	0	0	0	0.0
Other	1	31	35	9	0	76	9.7
Total	66	270	268	73	108	785	100.0

Table 2 shows the sightings reported to the International Ice Patrol in 1986, broken down by the source of the sighting and the size of iceberg sighted. It is important to note that the IIP side-looking airborne radar (SLAR) provided over 26% of the iceberg reports, the single largest source of icebergs sightings. Given that IIP SLAR reconnaissance usually takes place near the limit of all known ice, this sighting source becomes especially important.

Iceberg Reconnaissance and Communications

During the 1986 Ice Patrol year (from October 1, 1985 through September 30,1986), 63 aircraft sorties were flown in support of the International Ice Patrol. These included pre-season flights, ice observation and logistics flights during the season, and post-season flights. Pre-season flights determined iceberg concentrations north of 48°N to estimate the time when icebergs would threaten the North Atlantic shipping lanes in the vicinity of the Grand Banks of Newfoundland. During the active season, ice observation flights located the southwestern, southern, and southeastern limits of icebergs. Logistics flights were necessary due to aircraft maintenance problems. Post-season flights were made to retrieve parts and equipment from Gander and to close out all business transactions from the season.

U.S. Coast Guard aircraft, deployed from Coast Guard Air Station Elizabeth City, North Carolina, conducted all the aircraft missions. SLAR-equipped HC-130 aircraft were utilized exclusively for aerial ice reconnaissance, and HC-130 and HU-25A aircraft were used on logistics flights. Table 3 shows aircraft utilization during the 1986 season.

U.S. Coast Guard Communications Station Boston, Massachusetts, NMF/NIK, was the primary radio station used for the dissemination of the daily ice bulletins and facsimile charts after preparation by the Ice Patrol office in Groton. Other transmitting stations for the 0000Z and 1200Z ice bulletins included Canadian Coast Guard Radio Station St. John's/VON, Canadian Forces Radio Station Mill Cove/CFH, and U.S. Navy LCMP Broadcast Stations Norfolk/NAM; Thurso, Scotland; and Keflavik, Iceland. Canadian Forces Station Mill Cove/CFH as well as AM Radio Station Bracknell/GFE, United Kingdom, are radiofacsimile broadcasting stations which used Ice Patrol limits in their broadcasts. Canadian Coast Guard Radio Station St. John's/ VON provided special broadcasts.

The International Ice Patrol requested that all ships transiting the area of the Grand Banks report ice sightings, weather, and sea surface temperatures via the above communications/radio stations. Response to this request is shown in Table 4, and Appendix A lists all contributors. Commander, International Ice Patrol extends a sincere thank you to all stations and ships which contributed.

Table 3. Aircraft Use During the 1986 IIP Year (October 1, 1985 to September 30, 1986)

Aircraft Deployment	Hours Flown
Pre-season	63.1
Regular season	294.5
Post season	22.2
Total	379.8

Iceberg Reconnaissance Sorties by Month

Month	Sorties	Flight hours
Feb	2	13.7
Mar	9	40.7
Apr	7	50.9
May	14	99.1
Jun	10	74.4
Jul	3	15.2
Total	45	294.0

Table 4. Iceberg and SST Reports

Number of ships furnishing Sea Surface Temperature (SST) reports	49
Number of SST reports received	274
Number of ships furnishing ice reports	211
Number of ice reports received	437
First Ice Bulletin	270000Z MAR 86
Last Ice Bulletin	031200Z JUL 86
Number of facsimile charts transmitted	97

Environmental Conditions 1986 Season

January: The mean pressure distribution in Figure 1 shows a normal location for the Icelandic Low, with stronger than normal pressure gradients surrounding it. A westerly flow brought drier, somewhat warmer conditions to Newfoundland, while a northerly flow brought near-normal conditions to Labrador (Table 5).

February: The Icelandic Low was deeper than normal and was south and west of its normal mean February location (Figure 2). The two Newfoundland stations had colder and wetter conditions than normal (Table 5), the result of increased flow from the Labrador Sea, providing a combination of moisture and cooling from the pack ice. Labrador (Goose Bay) was at or above normal temperature and significantly drier than normal, the result of a stronger northerly flow.

March: March was significantly colder for all three stations, with precipitation below normal in Goose Bay and Gander and above normal in St. John's. This pattern was caused by a deeper than normal Icelandic Low, causing a colder, more westerly flow over the region (Figure 3). St. John's received moist marine flow from the Gulf of St. Lawrence while Gander and Goose Bay were under the influence of drier continental air.

April: The Icelandic Low was farther east than normal, setting up southerly, even southeasterly flow over Newfoundland and Labrador (Figure 4). April was much warmer at all three locations and significantly wetter in Newfoundland. These conditions were caused by the more southerly flow, bringing warm, moist marine air from the Atlantic, without the continental influence that normally moderates conditions.

May: The mean surface pressure distribution was close to normal during May (Figure 5). The below-normal precipitation was caused by the trough-like feature south of Newfoundland, causing flow south of the island rather than over it.

June: A more southerly flow over Newfoundland in June (Figure 6), brought moister, slightly warmer marine air, while Labrador received cooler, moister marine air from the Labrador Sea (Table 5).

July: Labrador and Newfoundland were cut off from their normal southerly/southwesterly flow (Figure7). As a result, all three stations were cooler than normal. The two Newfoundland stations received a northeasterly flow, bringing above normal precipitation, while Labrador had a westerly flow, bringing continental air and below normal precipitation.

NOTE: Temperature and precipitation data for Nain, Labrador, are compared to 1985 values in Table 5. The reporting station at Hopedale, Labrador, was closed in 1984 and the Nain station opened. An historical mean for Nain does not exist.

Table 5. Environmental Conditions for 1986 IIP Season

	Station	Temp °C Monthly Mean	Temp °C Diff. from Norm.	Total Precipitation (mm)	% of Normal Precipitation	% of Normal Snowfall
OCT 1985	Nain	1.3	-0.5	56.7	76.4%	
	Goose	1.8	-0.9	61.2	79.9%	90.7%
	Gander	4.5	-1.5	72.3	69.1%	229.5%
	St. John's	5.8	-1.1	85.9	59.0%	250.0%
NOV	Nain	-3.7	1.1	87.7	160.9%	
	Goose	-5.1	-1.3	24.3	32.3%	31.2%
	Gander	-1.2	-3.0	71.8	66.9%	74.2%
	St. John's	0.3	-3.1	103.7	63.8%	144.8%
DEC	Nain	-11.7	5.5	229.8	295.0%	
	Goose	-14.2	-1.2	32.7	45.0%	51.4%
	Gander	-5.3	-1.5	95.0	87.8%	98.4%
	St. John's	-3.2	-1.7	113.9	70.7%	124.0%
JAN 1986	Nain	-16.5	-3.9	125.3	59.5%	
	Goose	-15.6	0.8	76.6	103.0%	117.4%
	Gander	4.8	1.4	73.4	67.3%	39.4%
	St. John's	-2.7	1.2	117.3	75.3%	64.7%
FEB	Nain	-13.8	2.4	74.2	59.7%	
	Goose	-14.0	0.5	21.9	36.1%	47.4%
	Gander	-7.5	-0.7	124.8	125.2%	138.8%
	St. John's	-5.5	-1.0	184.9	132.0%	87.9%
MAR	Nain	-17.6	-5.6	20.7	16.7%	
	Goose	-12.9	-4.3	44.3	61.4%	65.3%
	Gander	-5.9	-2.4	85.3	77.7%	114.8%
	St. John's	-3.8	-1.5	175.3	132.9%	71.2%
APR	Nain	-3.3	4.8	44.8	37.5%	
	Goose	0.8	2.5	61.0	99.7%	27.2%
	Gander	4.1	3.2	130.0	139.5%	18.7%
	St. John's	4.2	3.0	129.2	111.8%	12.7%
MAY	Nain	3.5	2.5	31.4	60.1%	
	Goose	7.8	11.5	44.8	70.2%	32.6%
	Gander	7.1	0.9	45.0	64.3%	145.0%
	St. John's	6.1	0.7	43.4	42.6%	182.9%
JUN	Nain	3.6	-3.3	114.9	512.9%	
	Goose	9.2	-2.1	115.9	124.5%	43.2%
	Gander	12.1	0.3	96.8	120.5%	42.9%
	St. John's	11.9	1.0	130.2	152.1%	*
JUL	Nain	9.1	-1.7	59.1	66.0%	
	Goose	13.3	-2.5	87.8	83.5%	*
	Gander	14.0	-2.5	113.2	164.1%	*
	St. John's	13.0	-2.5	87.8	105.7%	*
AUG	Nain	11.2	1.0	68.7	149.3%	
	Goose	15.4	-3.9	122.4	118.6%	*
	Gander	16.0	0.4	61.8	63.5%	*
	St. John's	15.1	-0.2	60.6	49.8%	*
SEP	Nain	7.4	0.6	38.8	64.1%	
	Goose	7.7	-1.4	115.2	136.3%	*
	Gander	9.0	-6.6	138.5	170.6%	*
	St. John's	9.7	-6.2	118.1	105.4%	*

* No snowfall recorded during this month

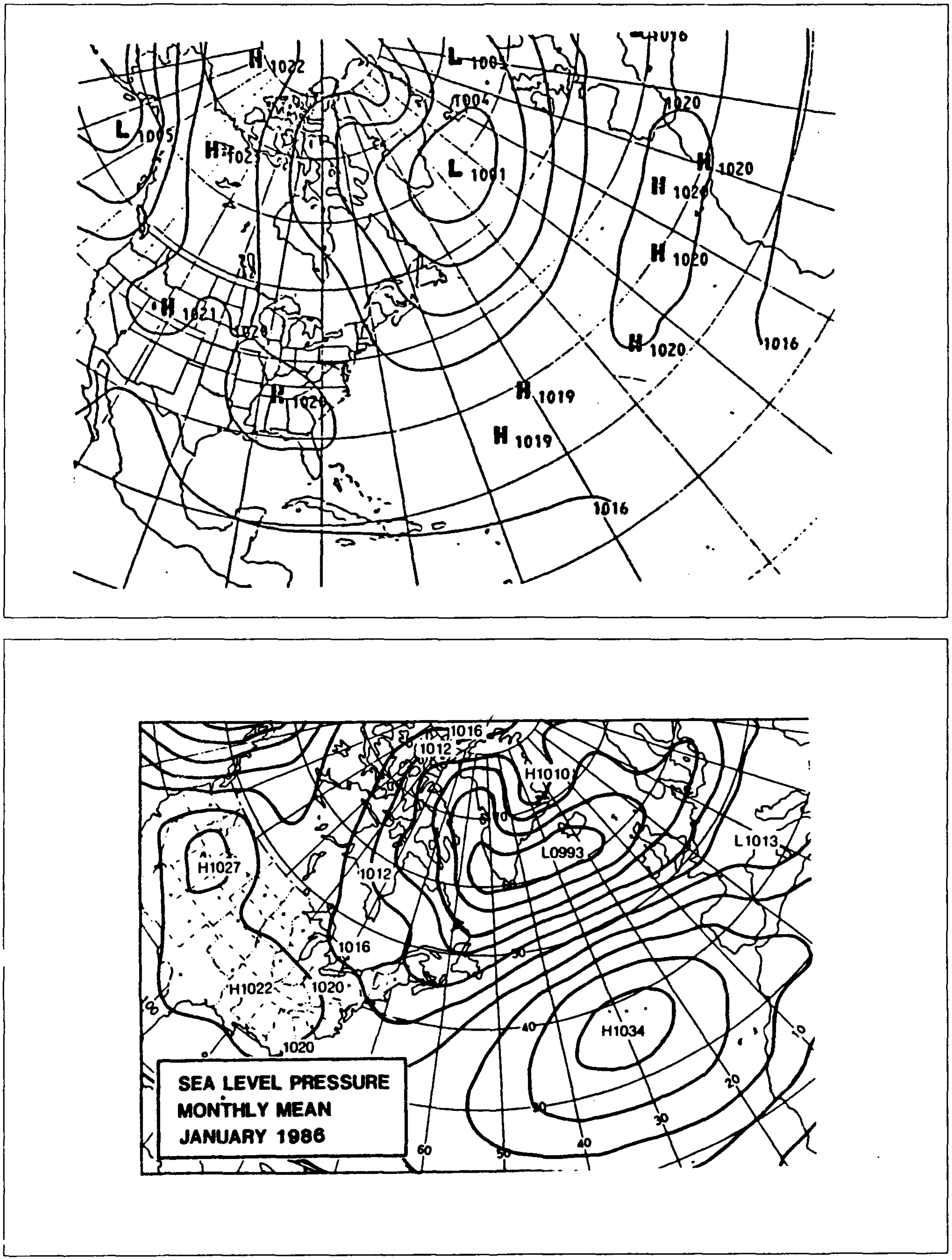
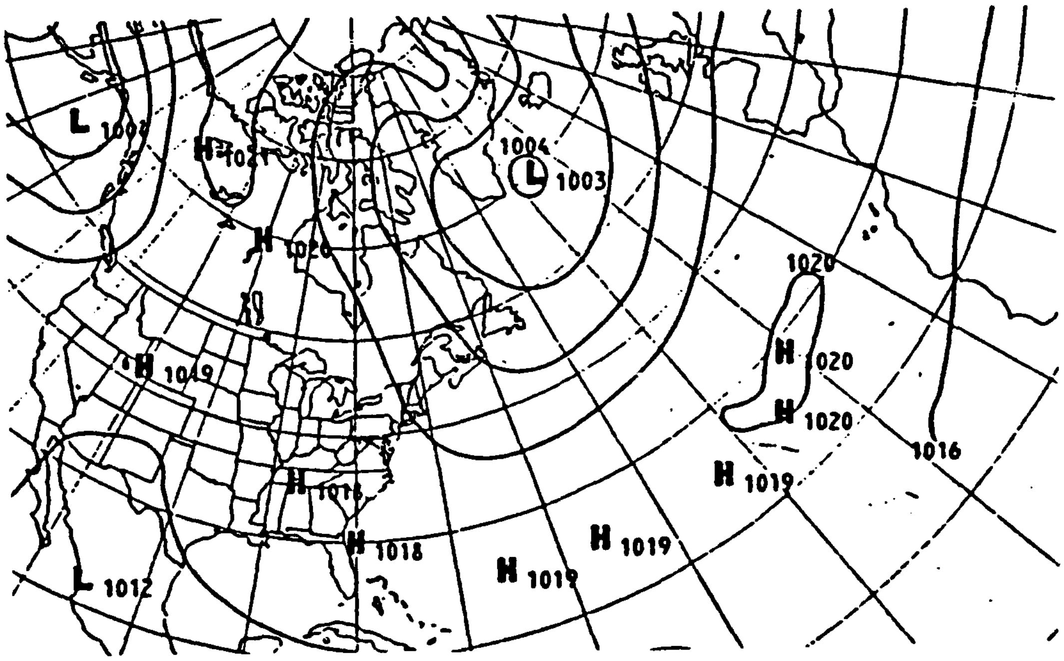


Figure 1. January 1986. Comparison of monthly mean surface pressure (bottom) with January historical average, 1948 - 1970 (top).



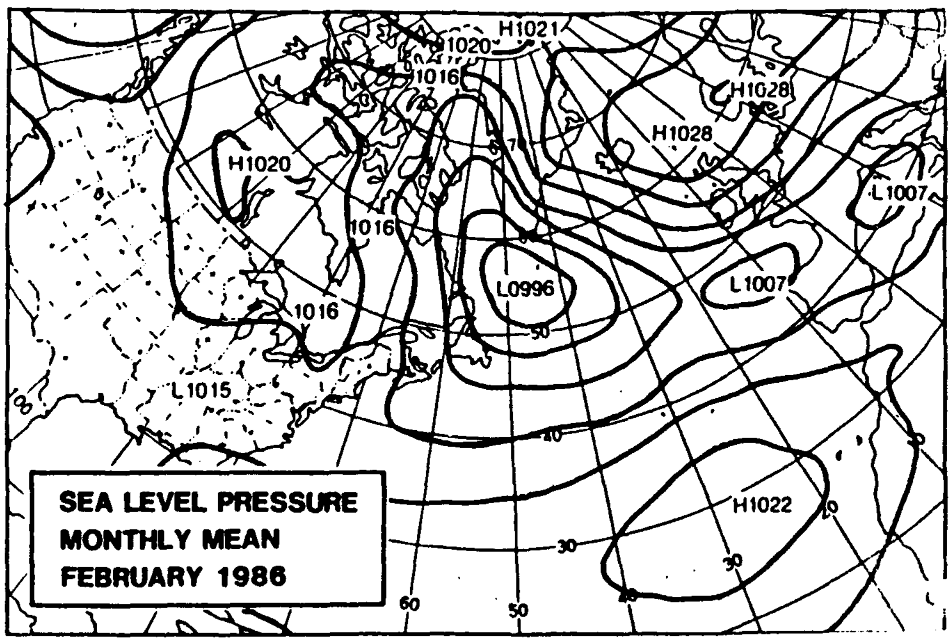
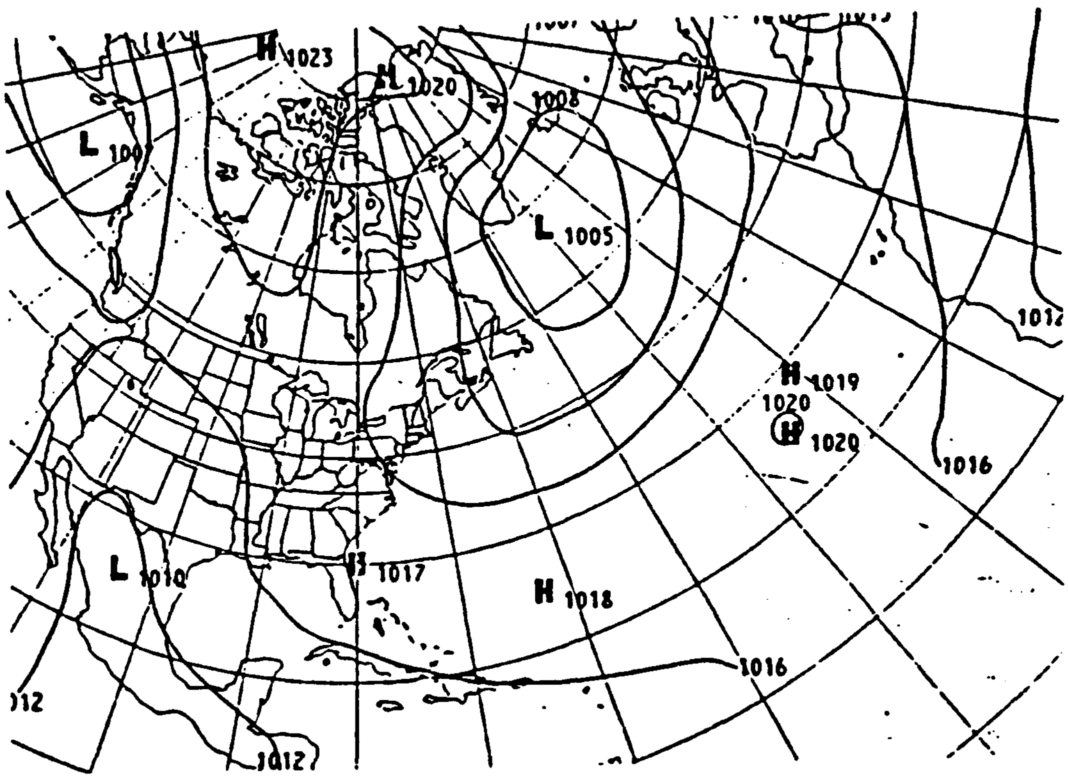


Figure 2. February 1986



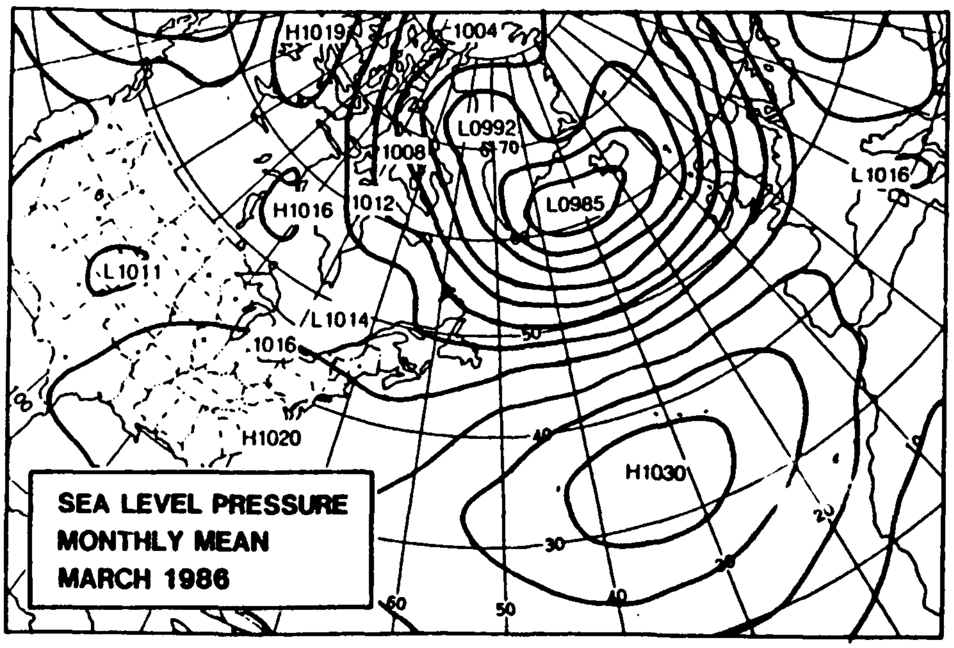
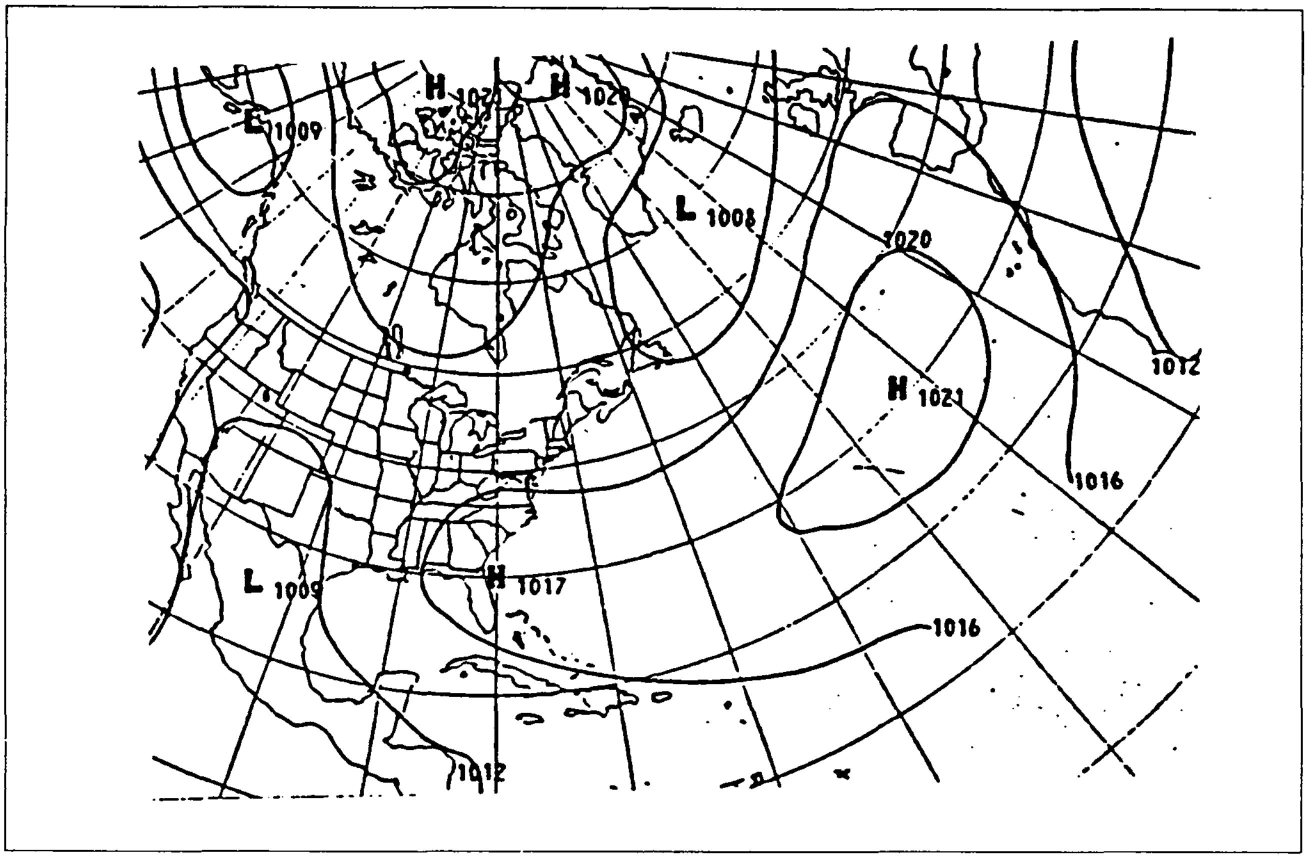


Figure 3. March 1986



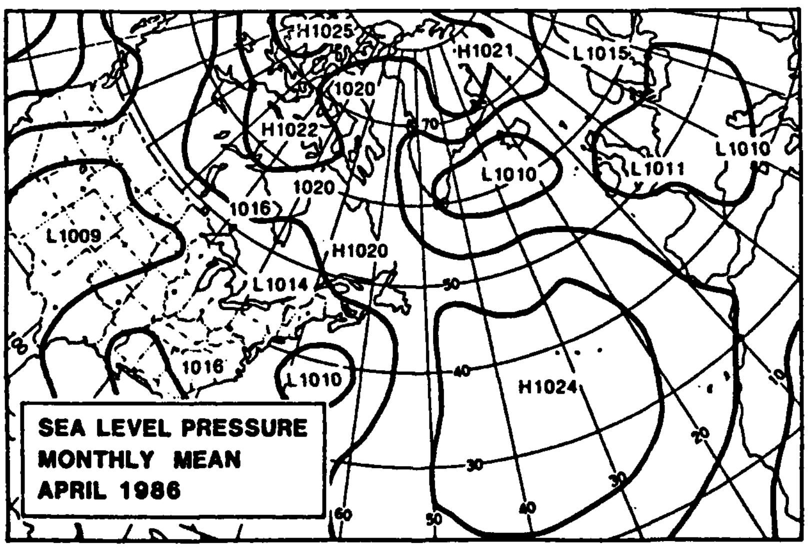


Figure 4. April 1986

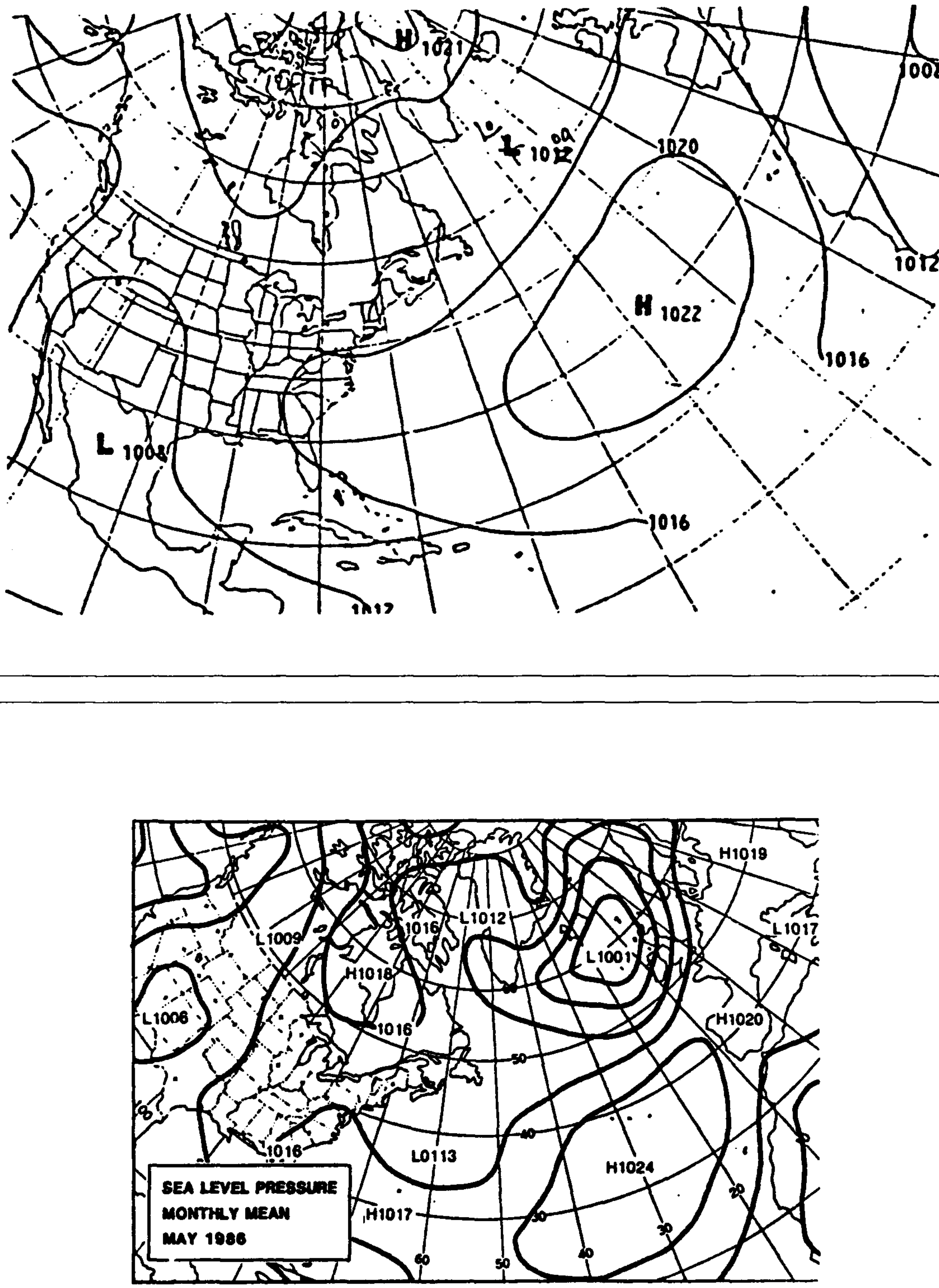
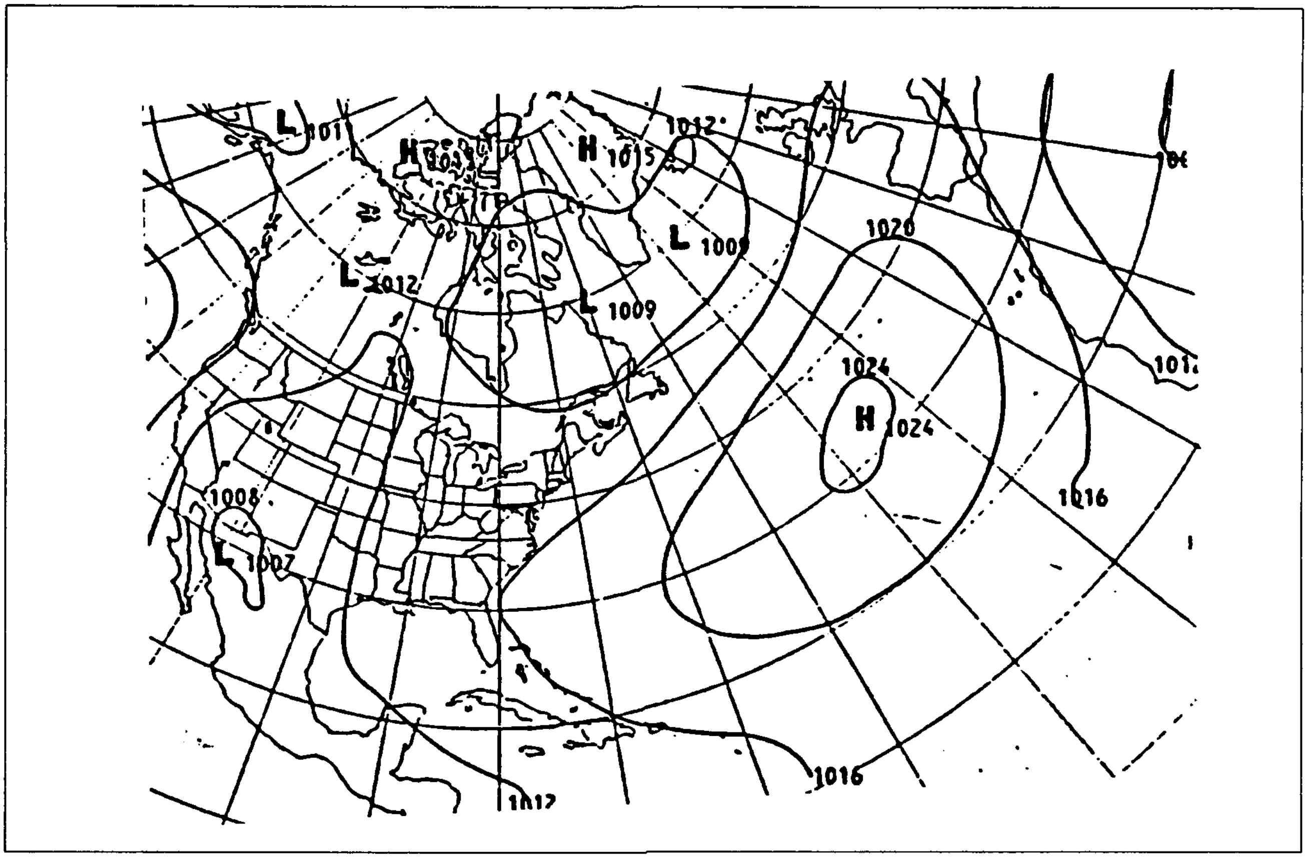


Figure 5. May 1986



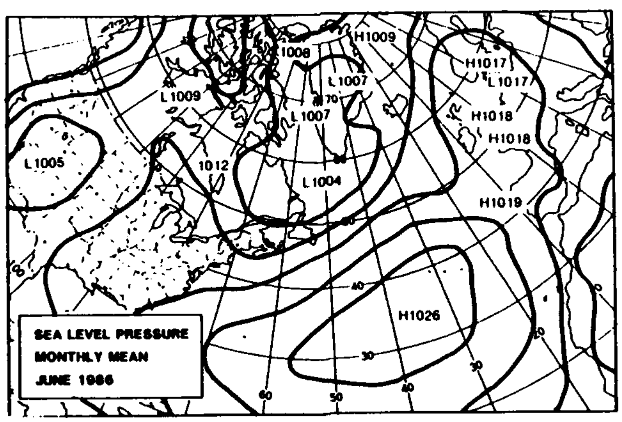
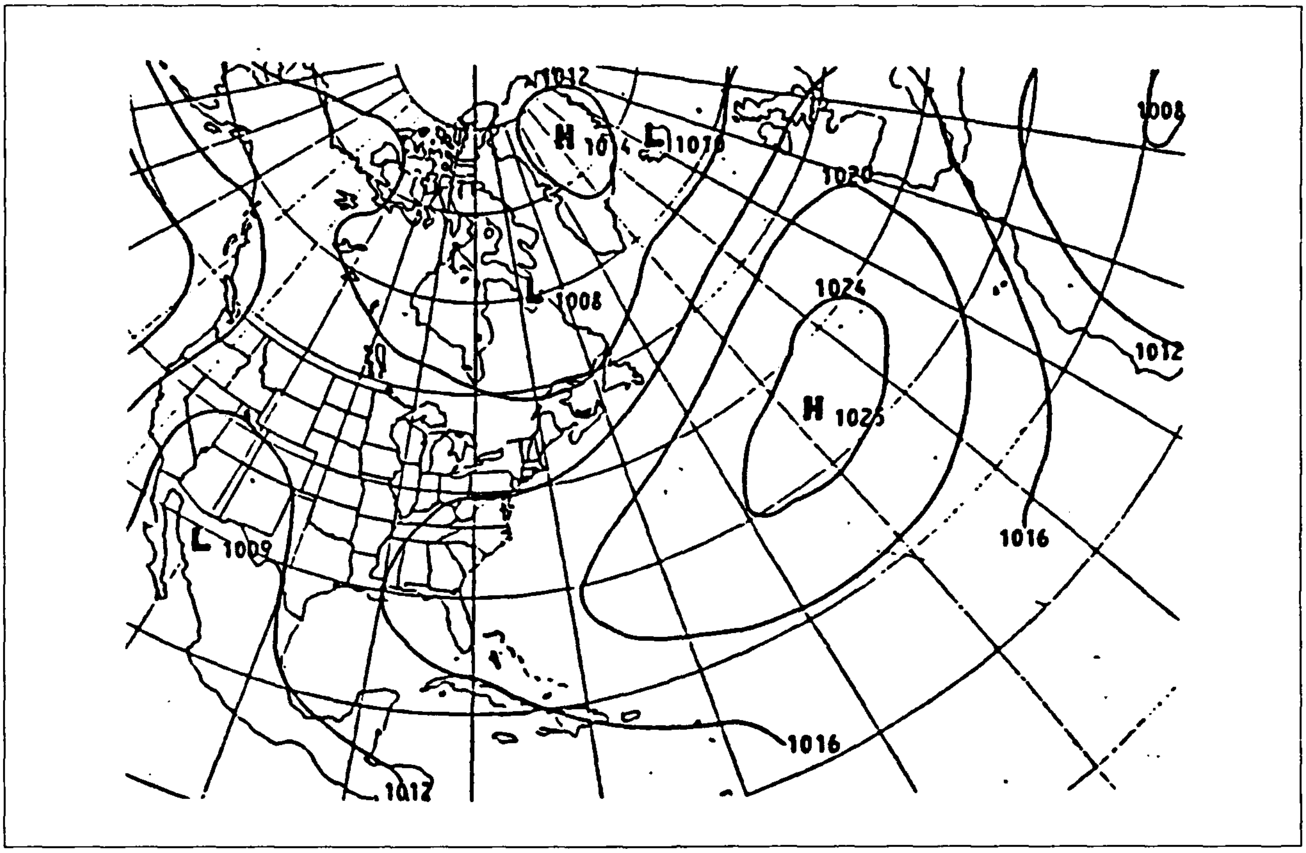


Figure 6. June 1986



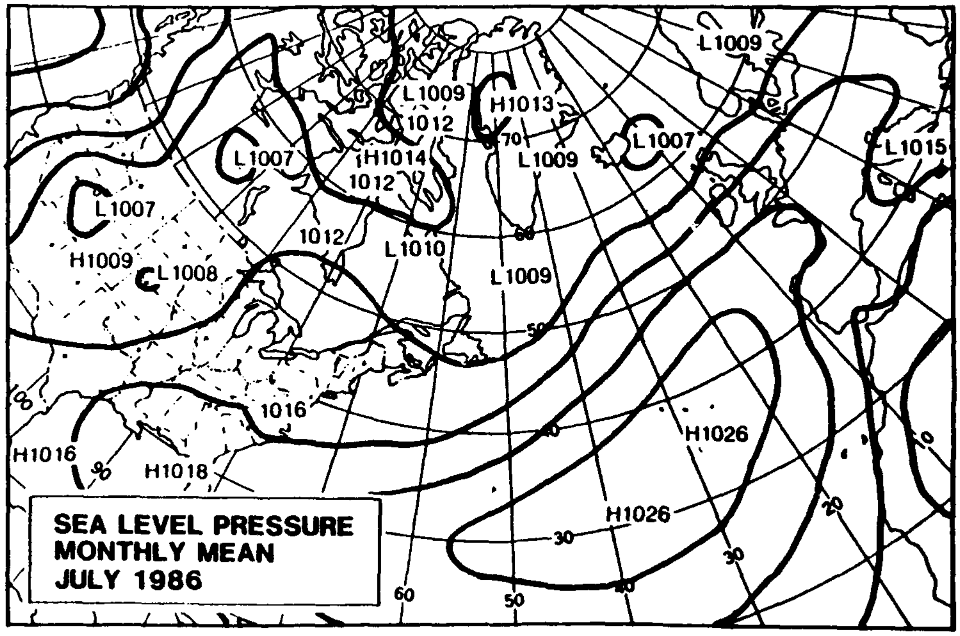


Figure 7. July 1986

Ice Conditions 1986 Season

October - November 1985: No sea ice was seen south of 65°N during these two months (Figures 8 and 9), however, sea ice formation was at or ahead of normal north of 65°N, due to below normal temperatures (Table 5). There were no icebergs added to plot south of 52°N in October or November.

December 1985: By mid-December (Figure 10), under the influence of continued below normal temperatures, Ungava Bay, Hudson and Davis Straits and the Labrador coast all showed 9 - 10 tenths coverage with new and young ice. Some sea ice formation was also taking place in the bays and coves of the northern Gulf of St. Lawrence. Consolidated first year ice extended as far south as Resolution Island in Hudson Strait. There were no icebergs added to plot south of 52°N in December.

January 1986: Mid-January showed the advance of new/young ice to the northern Avalon Peninsula in eastern Newfoundland (Figure 11). The boundary of first year ice was virtually unchanged from mid-December. There were no icebergs added to plot south of 52°N in January.

February 1986: Under the influence of a strong northerly flow in February (Figure 2), the sea ice advanced south along the Labrador coast and first year ice reached almost to the Avalon Peninsula by mid-month (Figure 12). Six icebergs were added to plot south of 52°N in February, 3 of which were south of 48°N.

March 1986: The ice edge continued to advance south (Figure 13), with a tongue of 9-10 tenths first year ice extending out to the vicinity of Flemish Pass by mid-March. The westerly flow over the region produced areas of somewhat lighter sea ice concentration along the east coasts of Baffin Island, Labrador and Newfoundland. During March, 42 icebergs were added to plot south of 52°N, 40 of which were south of 48°N. The high proportion south of 48°N was caused by icebergs being carried south and east of the ice pack by the Labrador Current. The 1986 International Ice Patrol season opened on March 27 (Figure 19).

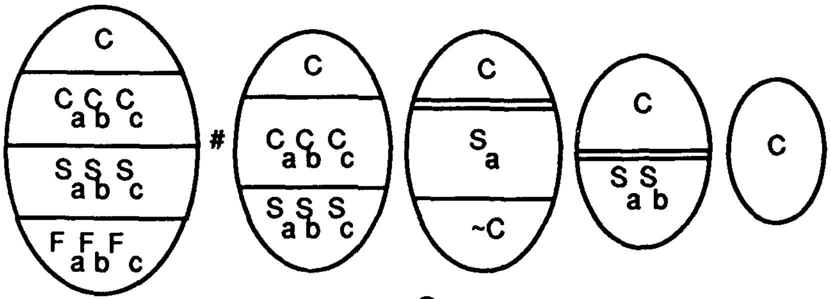
April 1986: The sea ice deteriorated and retreated along the Labrador and Newfoundland coasts during April (Figure 14), normally a month of continued sea ice development in the area. This retreat was caused by the warm conditions and southerly flow (Figure 4) described previously. During April, 60 icebergs were added to plot south of 52°N, all of which were south of 48°N. At mid-month, the main concentration of icebergs on plot at IIP was in Flemish Pass and across the northern half of the Grand Bank (Figure 20). By April 30, icebergs were widely distributed across the area south of 48°N (Figure 21).

May 1986: The ice edge continued to retreat in May and by mid-month, the Strait of Belle Isle was ice-free (Figure 15). Of the 74 icebergs added to plot south of 52°N in May, 59 were south of 48°N, the most icebergs south of that latitude for any month in 1986. The southernmost iceberg of the 1986 season was on May 10 at position 41° 06'N 48°06'W. By May 16 (Figure 22), fewer icebergs were seen on the Grand Bank and south of Flemish Pass, while the number north of 48°N had increased. On May 30 (Figure 23), only 7 icebergs remained south of 48°N and the total number of icebergs on plot had greatly decreased since mid-month.

June 1986: The ice edge was north of Goose Bay by mid-June and continuing to retreat (Figure 16). With 151 icebergs added to plot, June was the heaviest month for new icebergs, but only 24 new icebergs were south of 48°N. At mid-month, the only icebergs remaining south of 48°N were concentrated along the Newfoundland coast near Cape Race (Figure 24). On June 30, no icebergs remained south of 48°N (Figure 25).

July - September 1986: The ice edge continued to retreat in July and August (Figures 17 and 18) and by mid-September, there was no sea ice south of 65°N. There were no icebergs reported south of 48°N during July, August and September. The 1986 International Ice Patrol season closed on July 3 (Figure 26).

Table 6. Explanation of Sea Ice Symbols Used in Figures 8 — 18



C

Total ice concentration in the area in tenths.

$C_a C_b C_c$

Concentration of thickest (C_a), 2nd thickest (C_b), 3rd thickest (C_c).

$S_a S_b S_c$

Stage of development of thickest (S_a), 2nd thickest (S_b), 3rd thickest (S_c).

$F_a F_b F_c$

Concentration of ice within areas of strips and patches.

~C

Floe size of thickest (F_a), 2nd thickest (F_b), 3rd thickest (F_c).

Stage of Development

0	No stage of development
1	New ice
2	Nilas, ice rind
3	Young ice
4	Grey ice
5	Grey-white ice
6	First-year ice
7	Thin first-year ice
8	Thin first-year ice, 30-50 cm
9	Thin first-year ice, 50-70 cm
1 ·	Medium first-year ice
4 ·	Thick first-year ice
7 ·	Old ice
8 ·	Second-year ice
9 ·	Multi-year ice
▲	Icebergs
•	A trace of ice thicker than S_a
#	Fourth type, if $C_a C_b C_c$ do not add up to C

Floe Sizes

0	Pancake ice
1	Brash, small ice cake
2	Ice cake
3	Small floe
4	Medium floe
5	Big floe
6	Vast floe
7	Giant floe
8	Growlers and floebergs
9	Icebergs
/	Undetermined or unknown

Figure 8. October 15, 1985

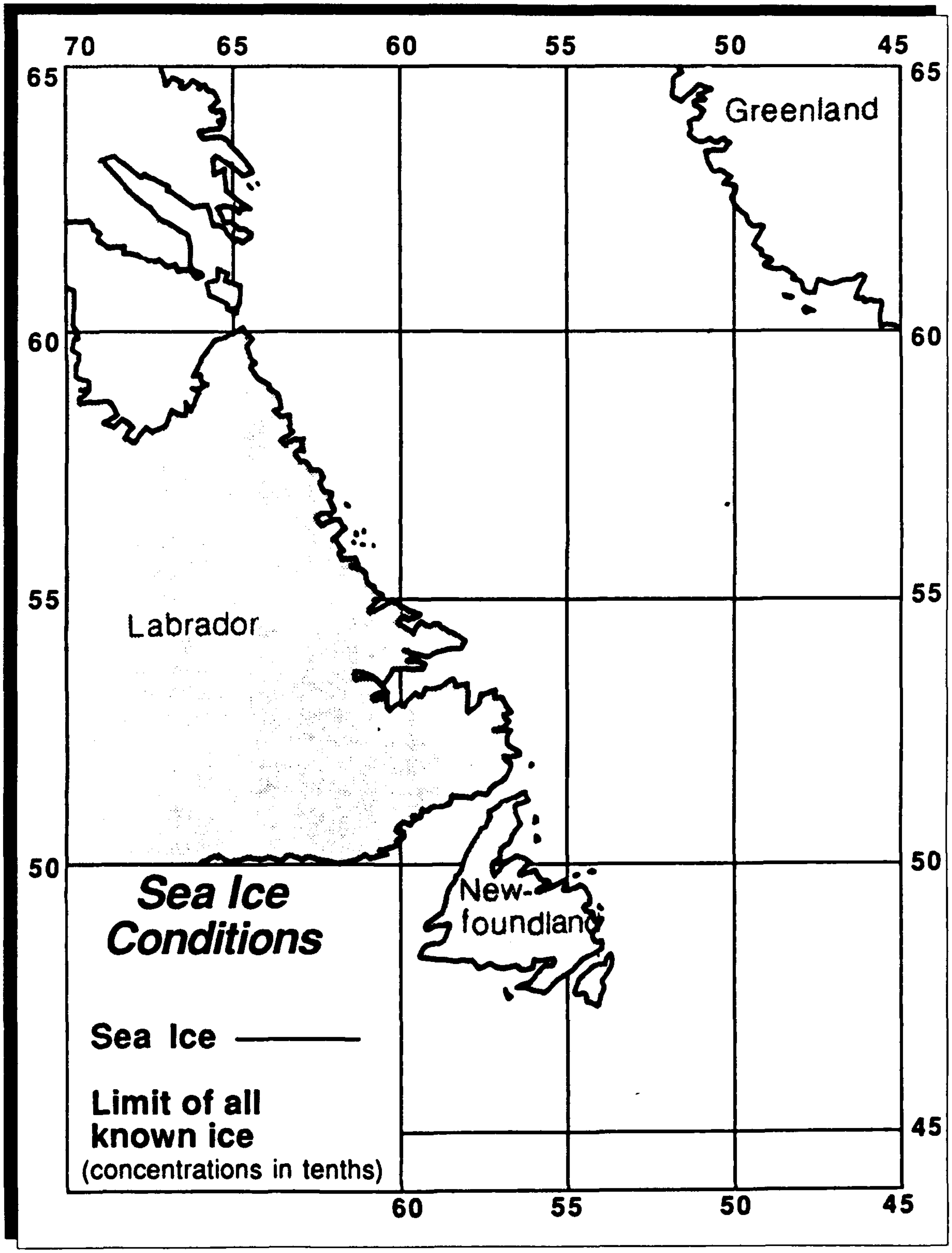


Figure 9. November 12, 1985

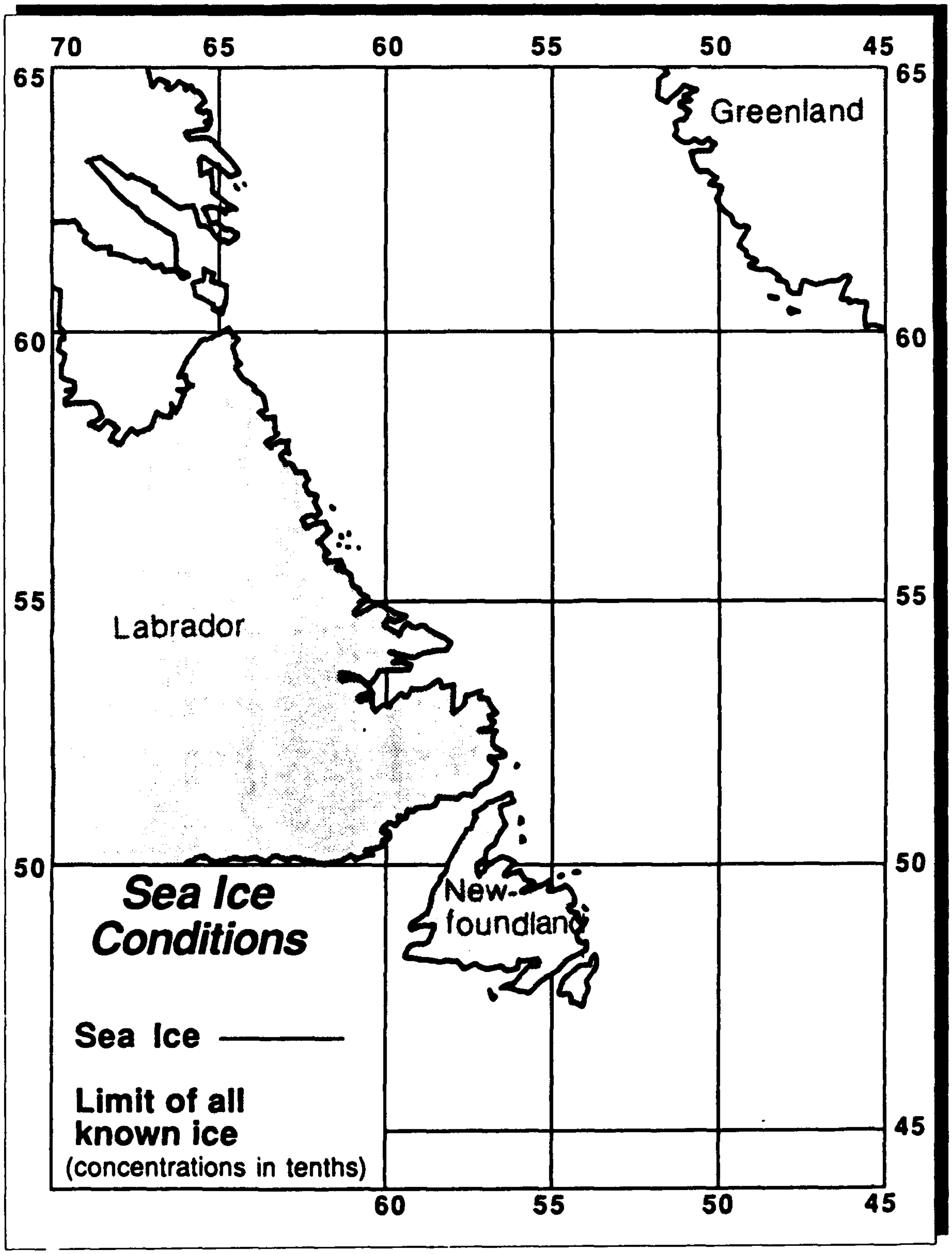


Figure 10. December 17, 1985

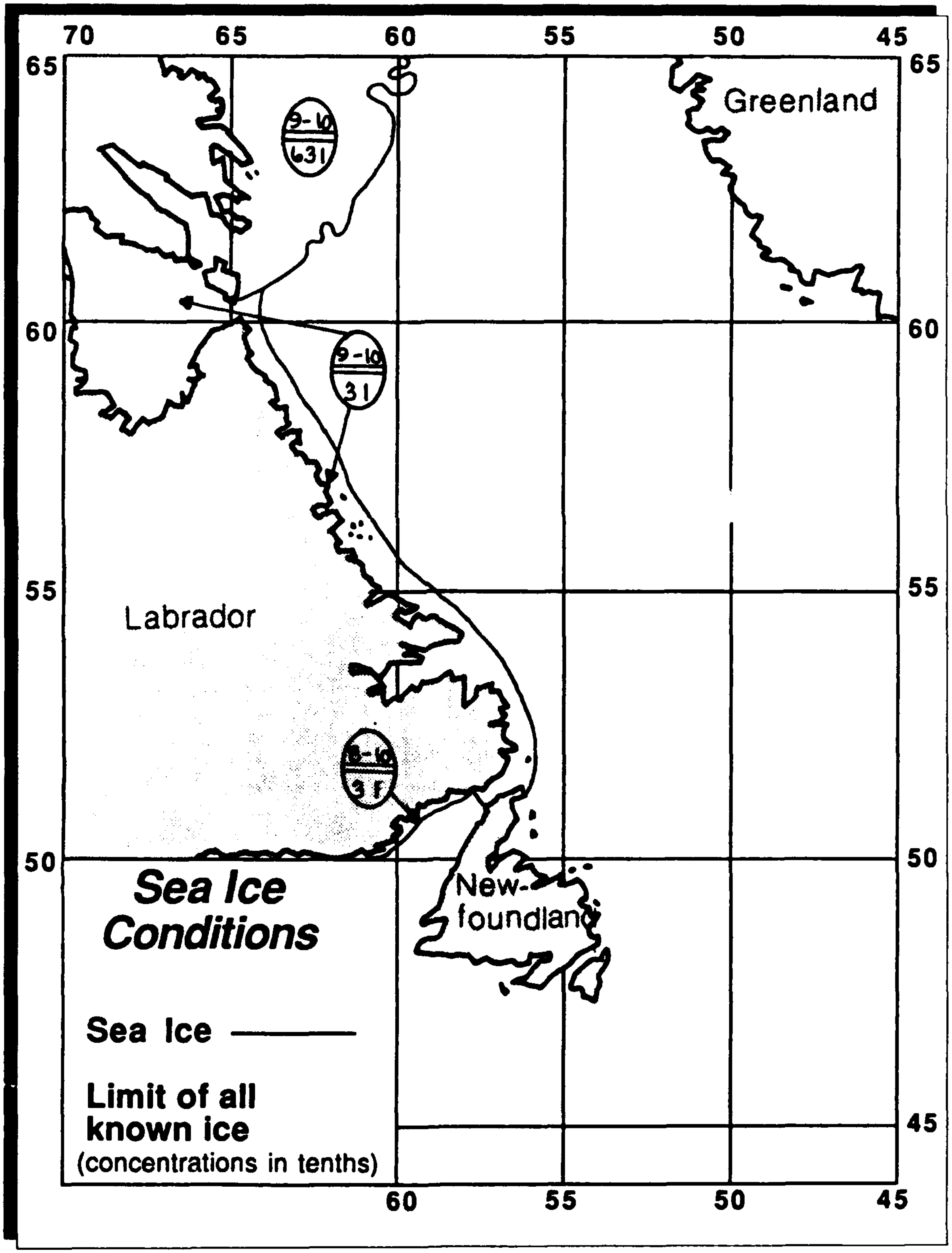


Figure 11. January 14, 1986

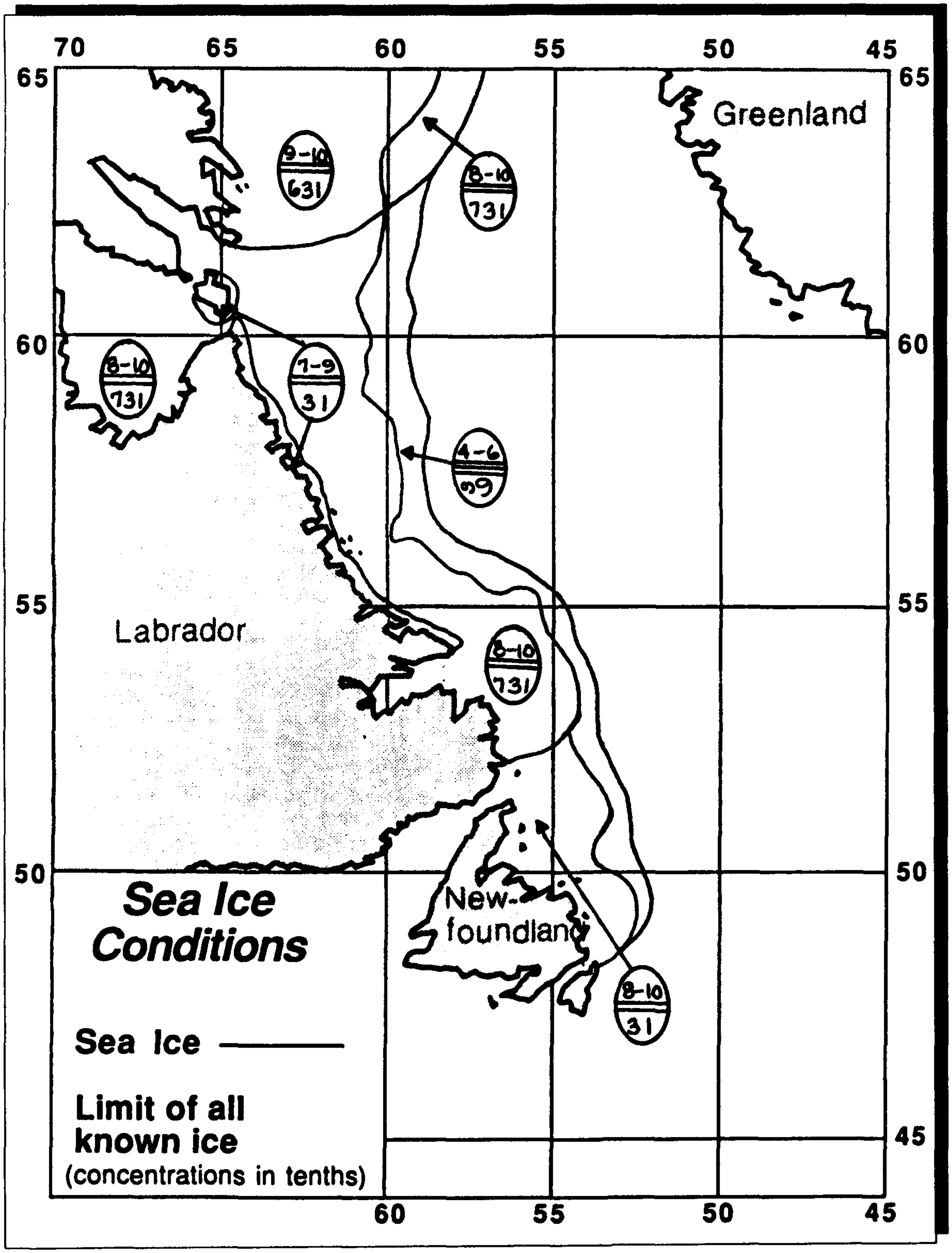


Figure 12. February 18, 1986

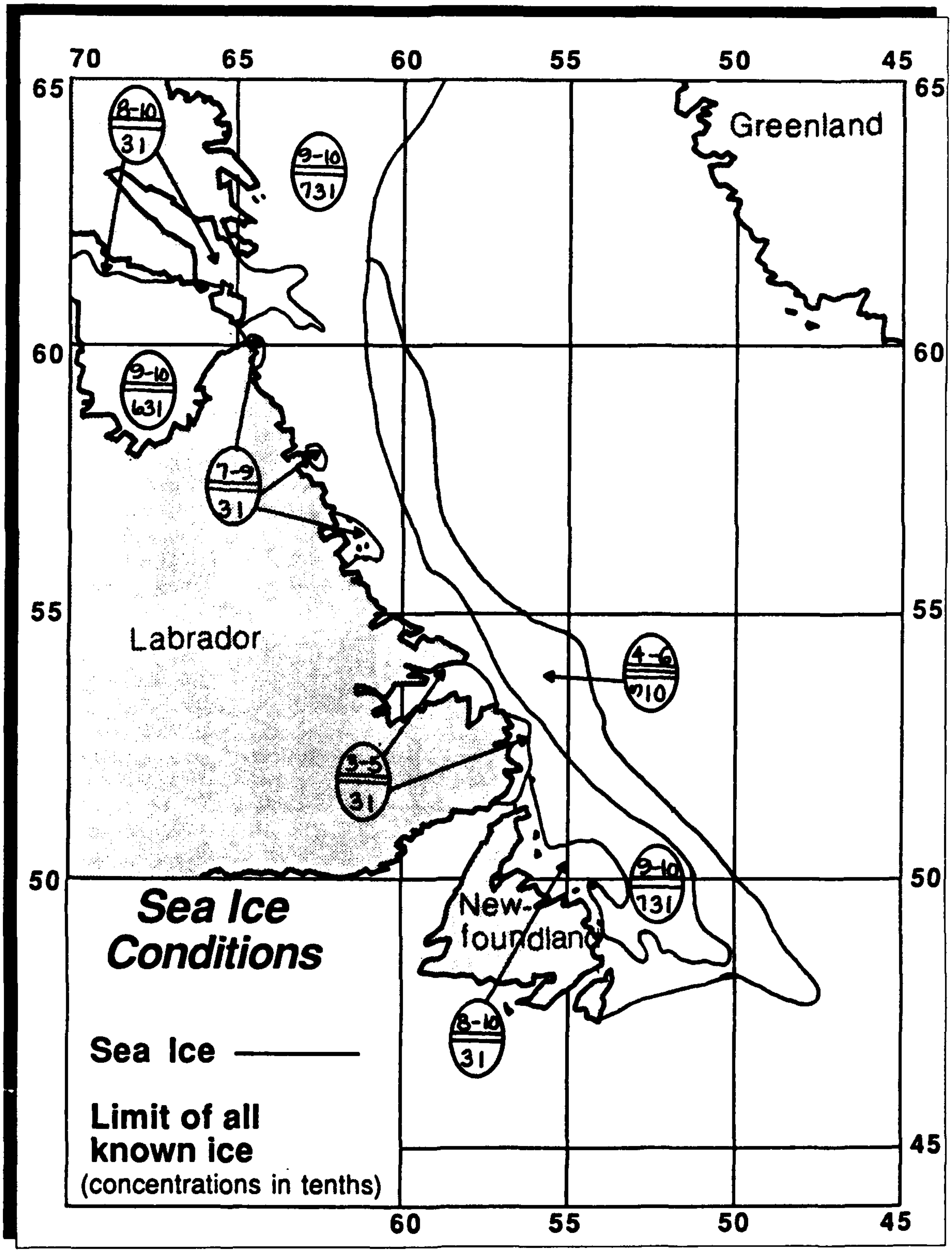


Figure 13. March 18, 1986

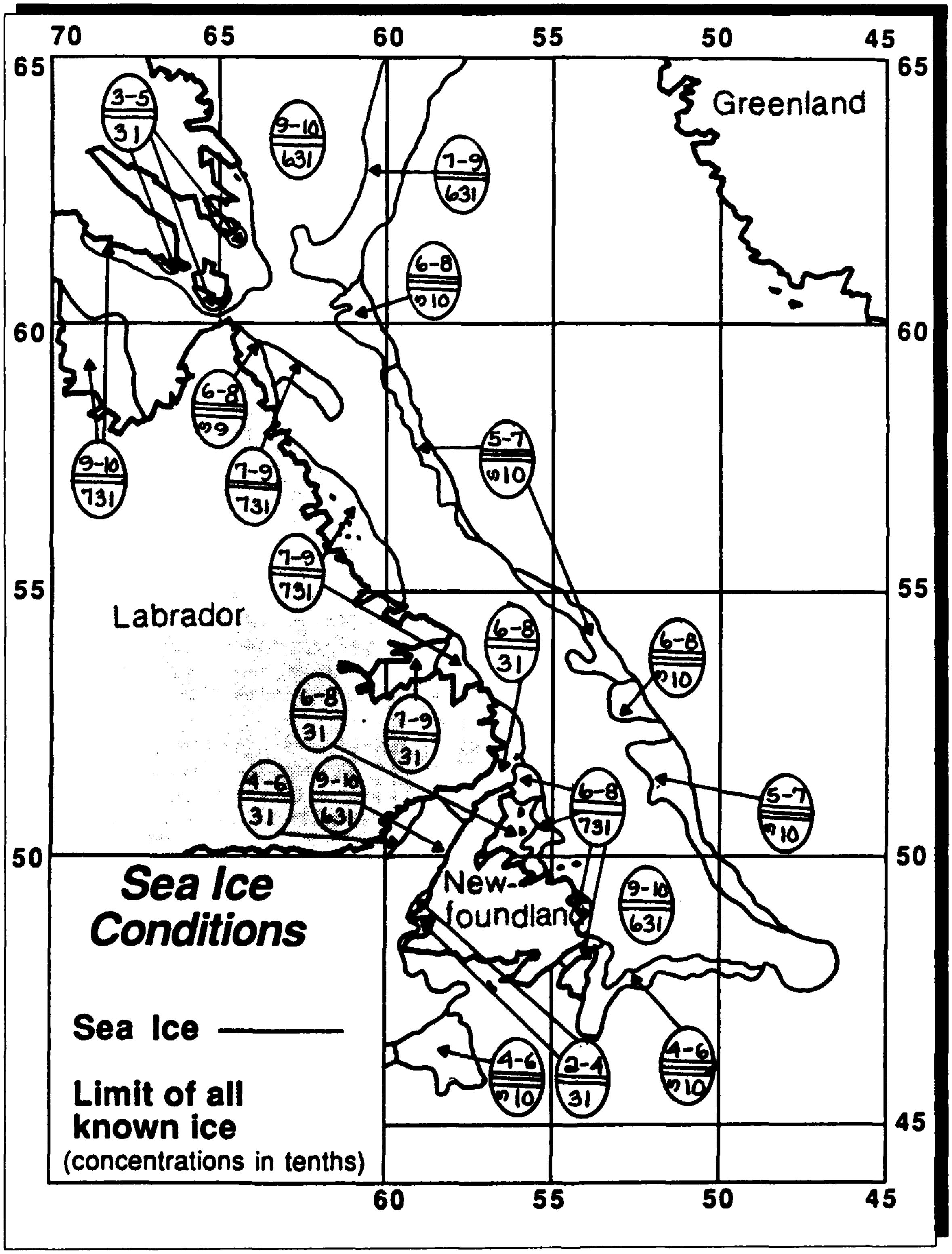


Figure 14. April 15, 1986

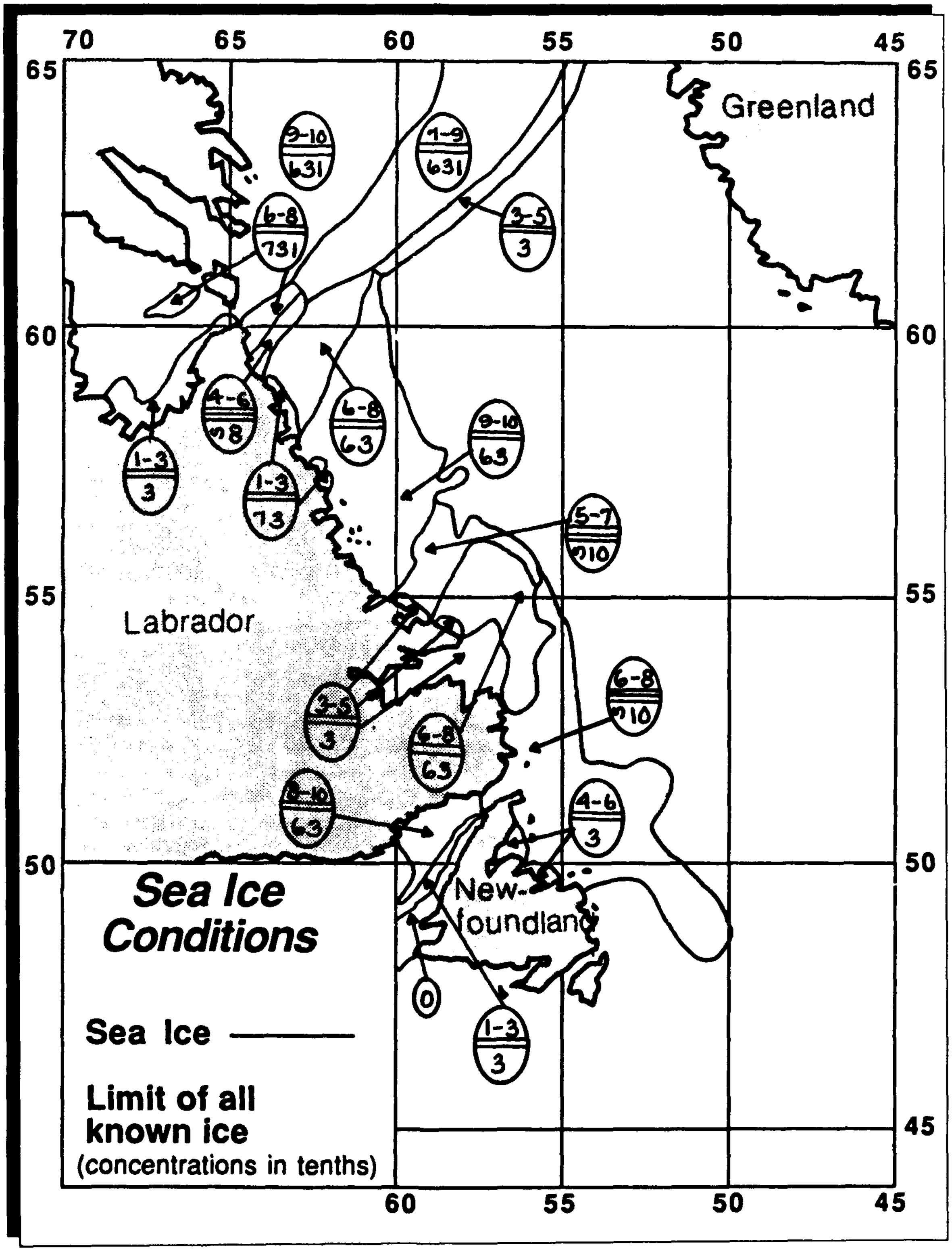


Figure 15. May 13, 1986

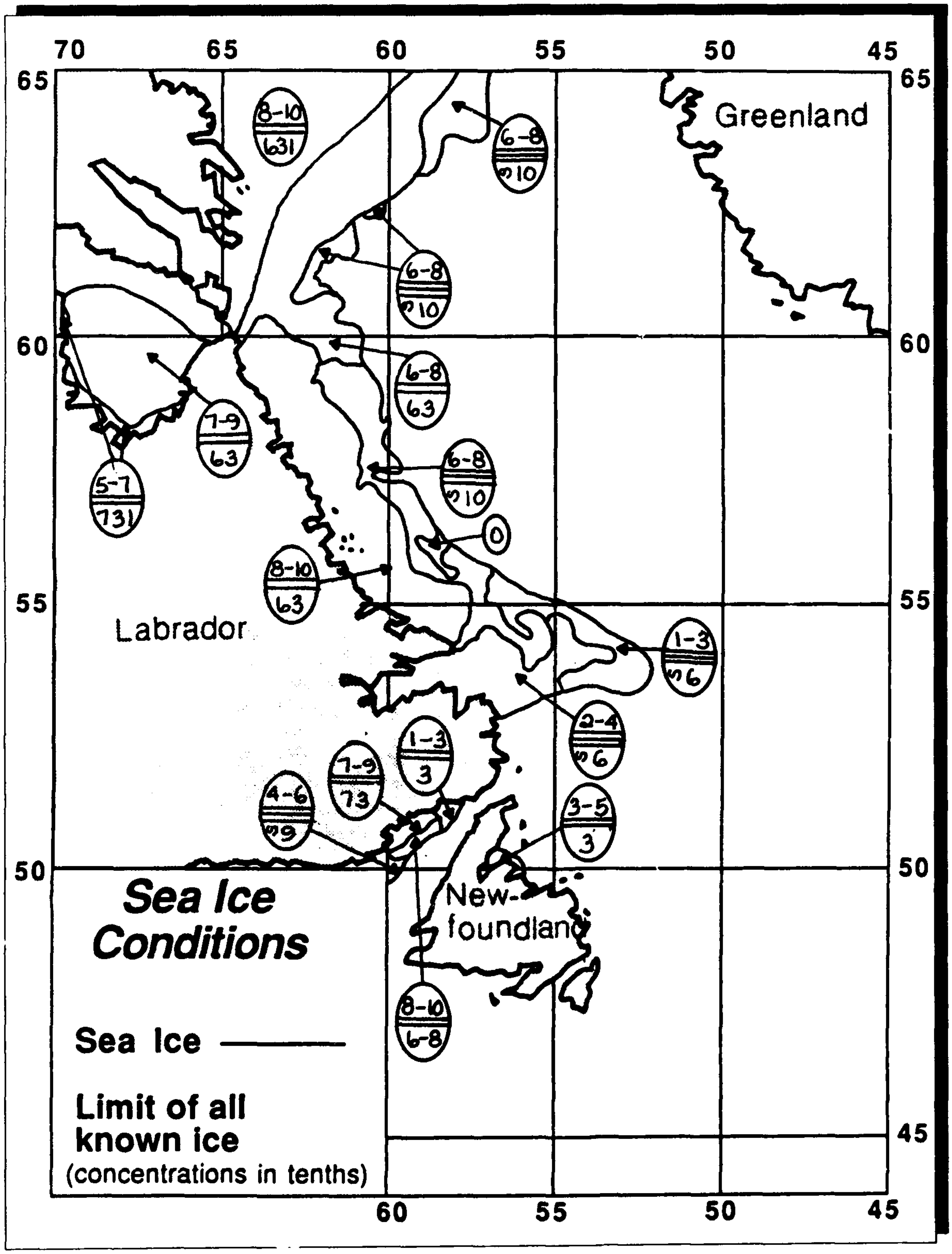


Figure 16. June 17, 1986

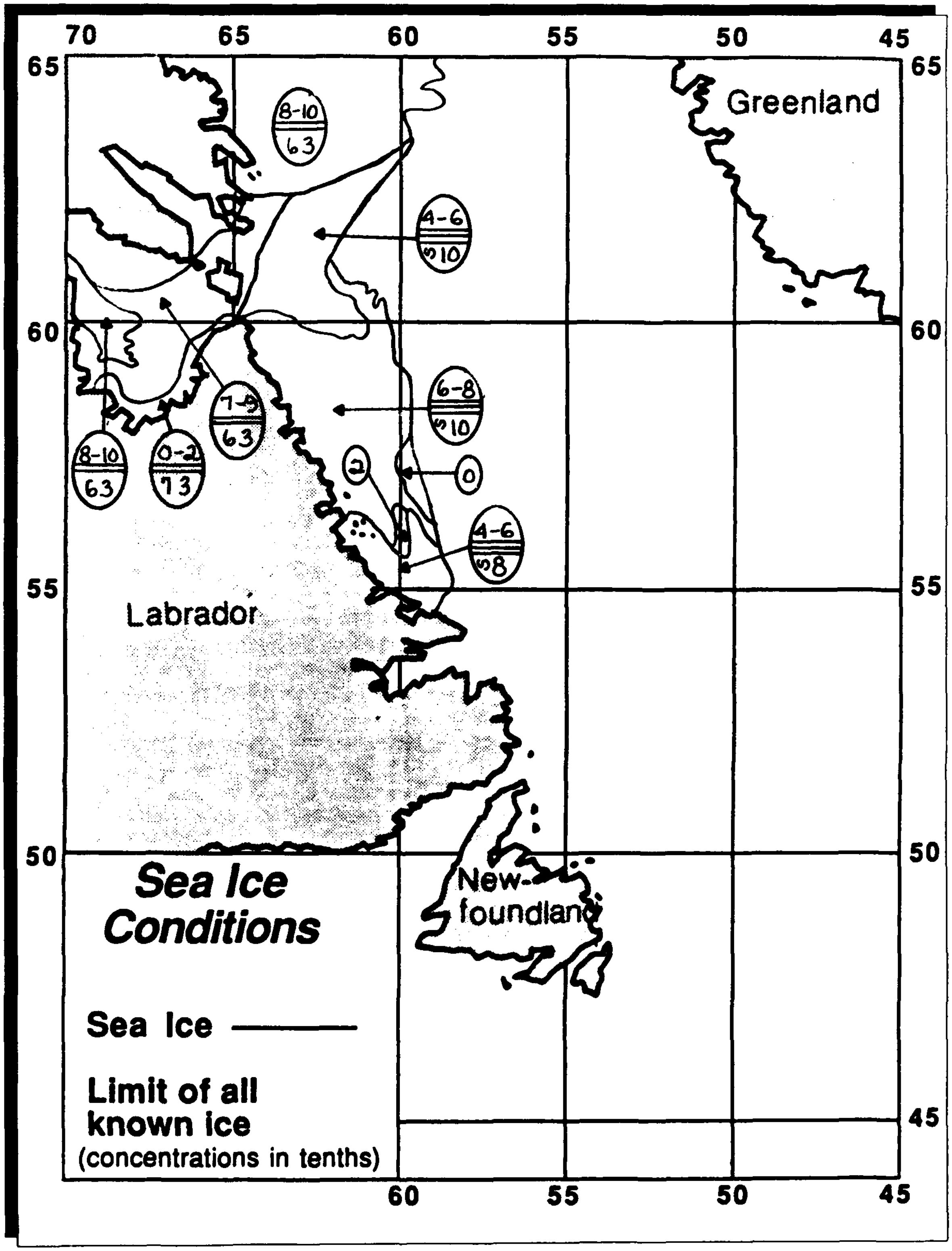


Figure 17. July 15, 1986

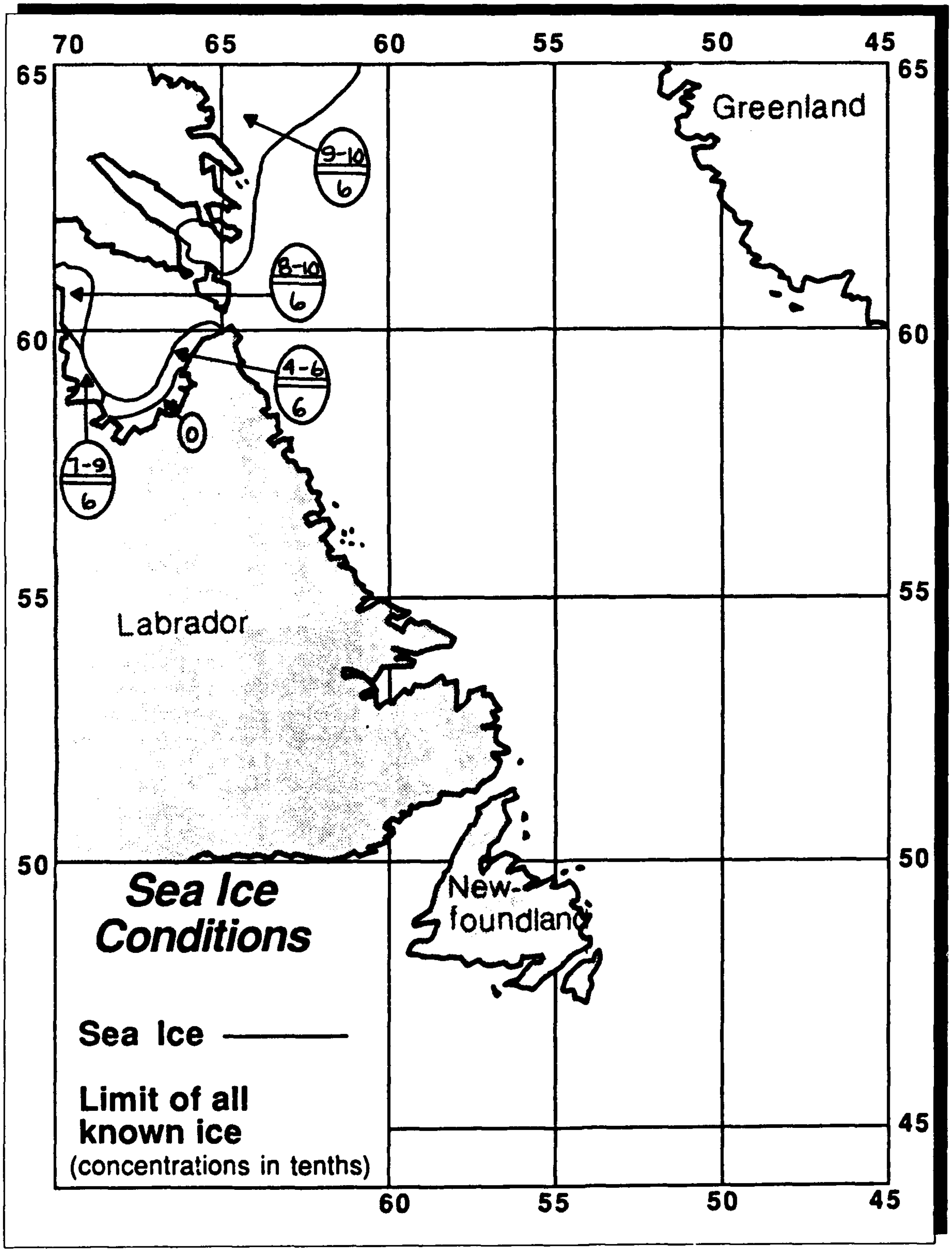


Figure 18. August 18, 1986

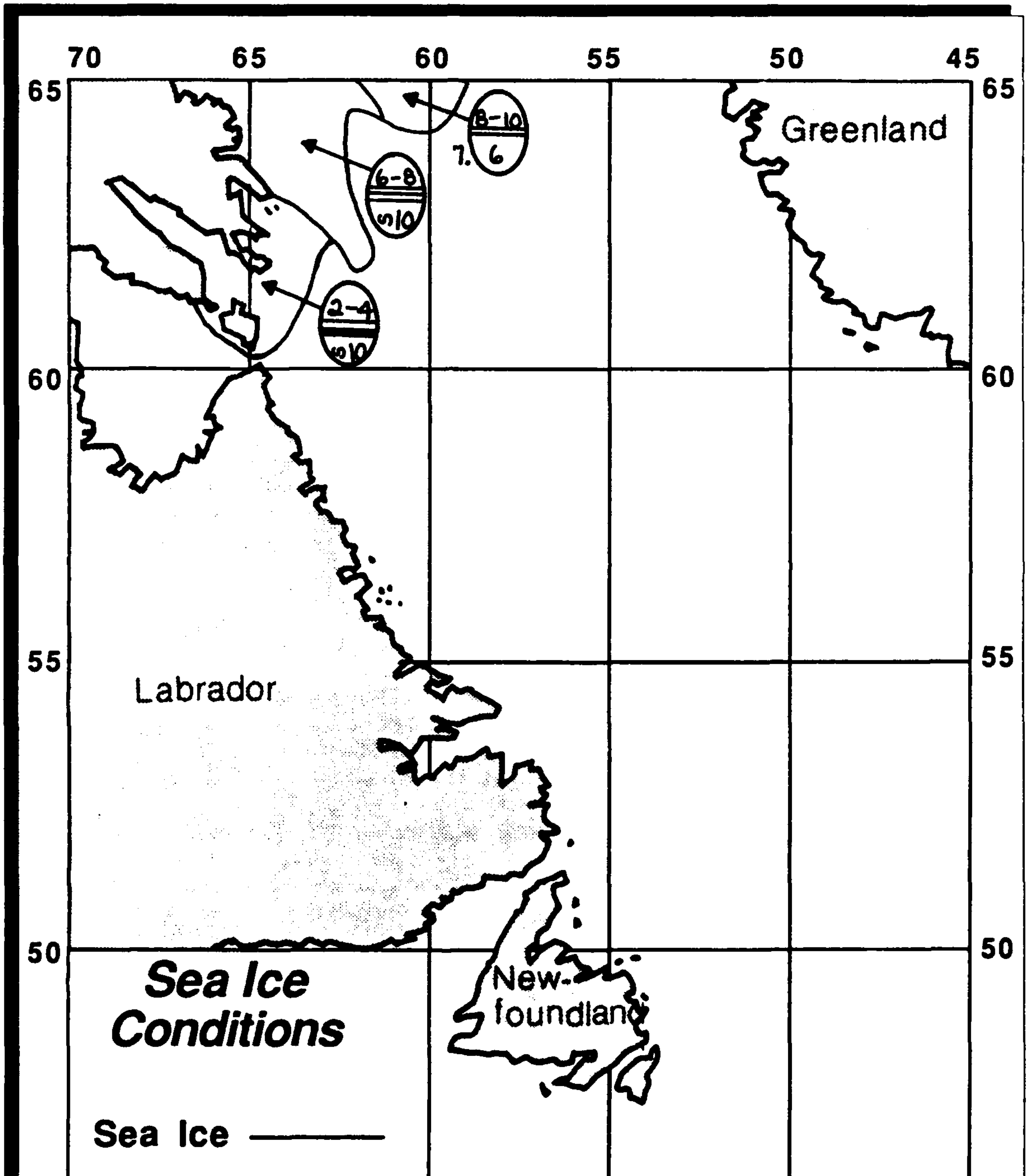


Figure 19. March 27, 1986

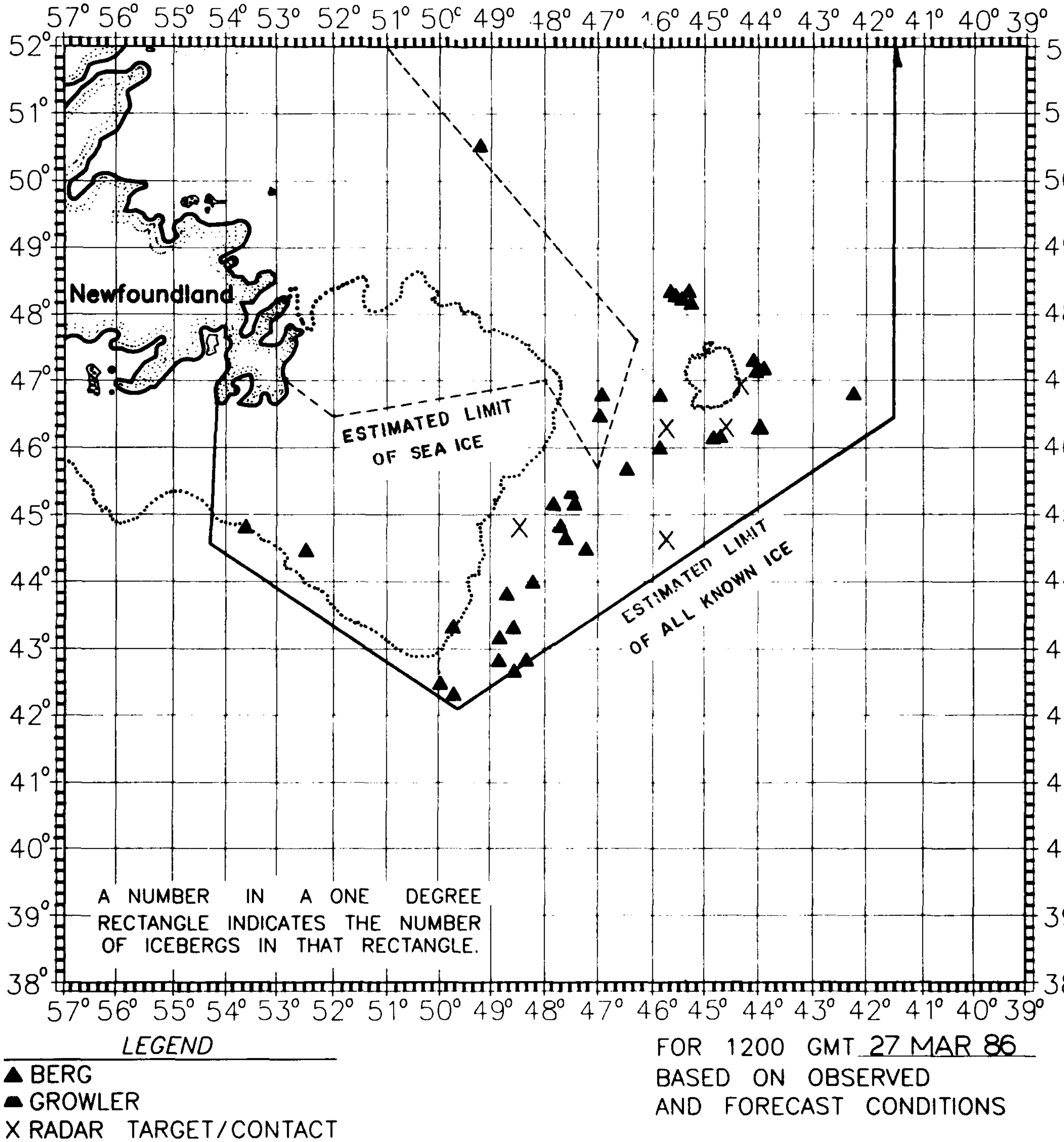
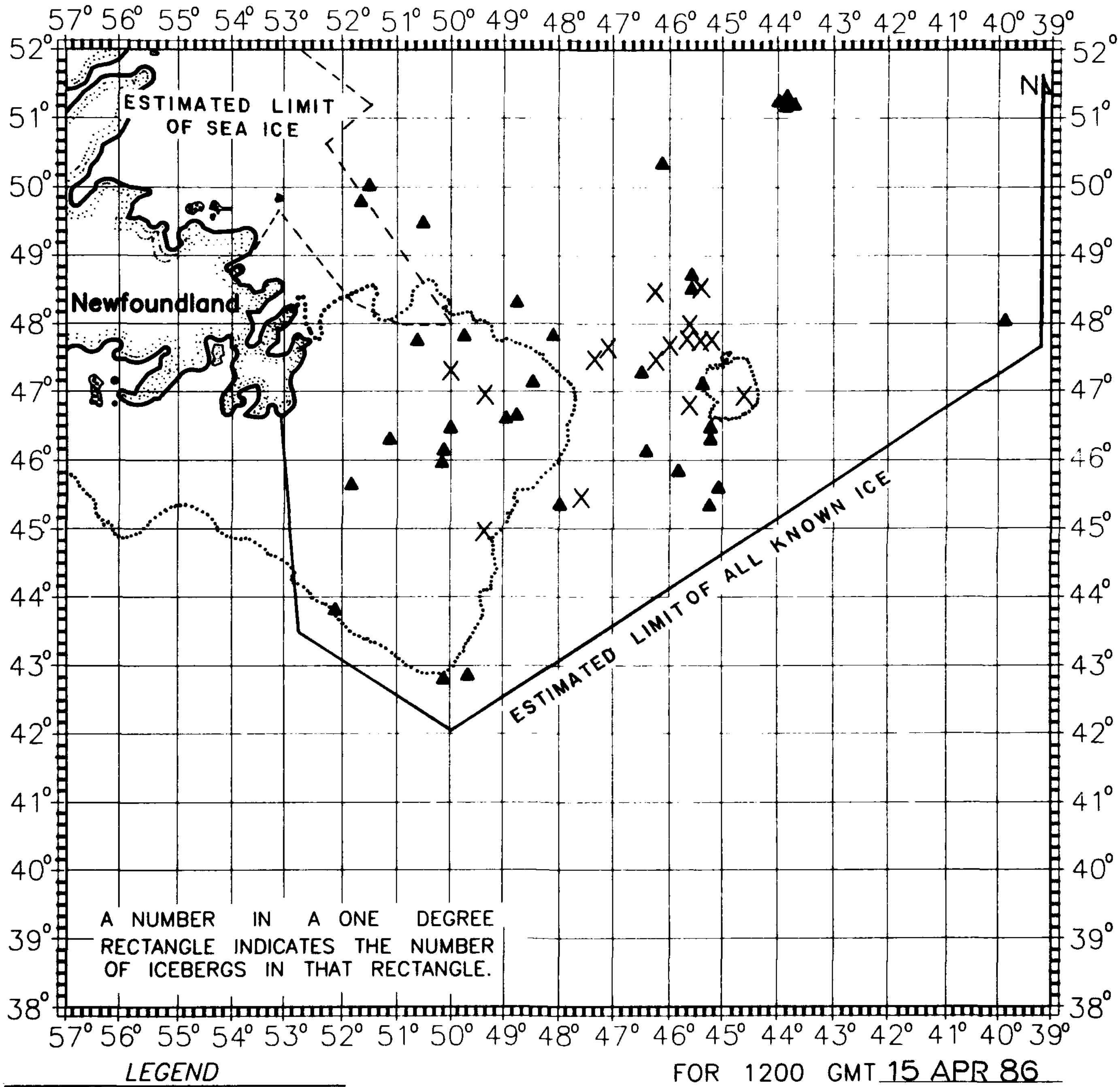


Figure 20. April 15, 1986



LEGEND

▲ BERG
▬ GROWLER
X RADAR TARGET/CONTACT

FOR 1200 GMT 15 APR 86
BASED ON OBSERVED
AND FORECAST CONDITIONS

Figure 21. April 30, 1986

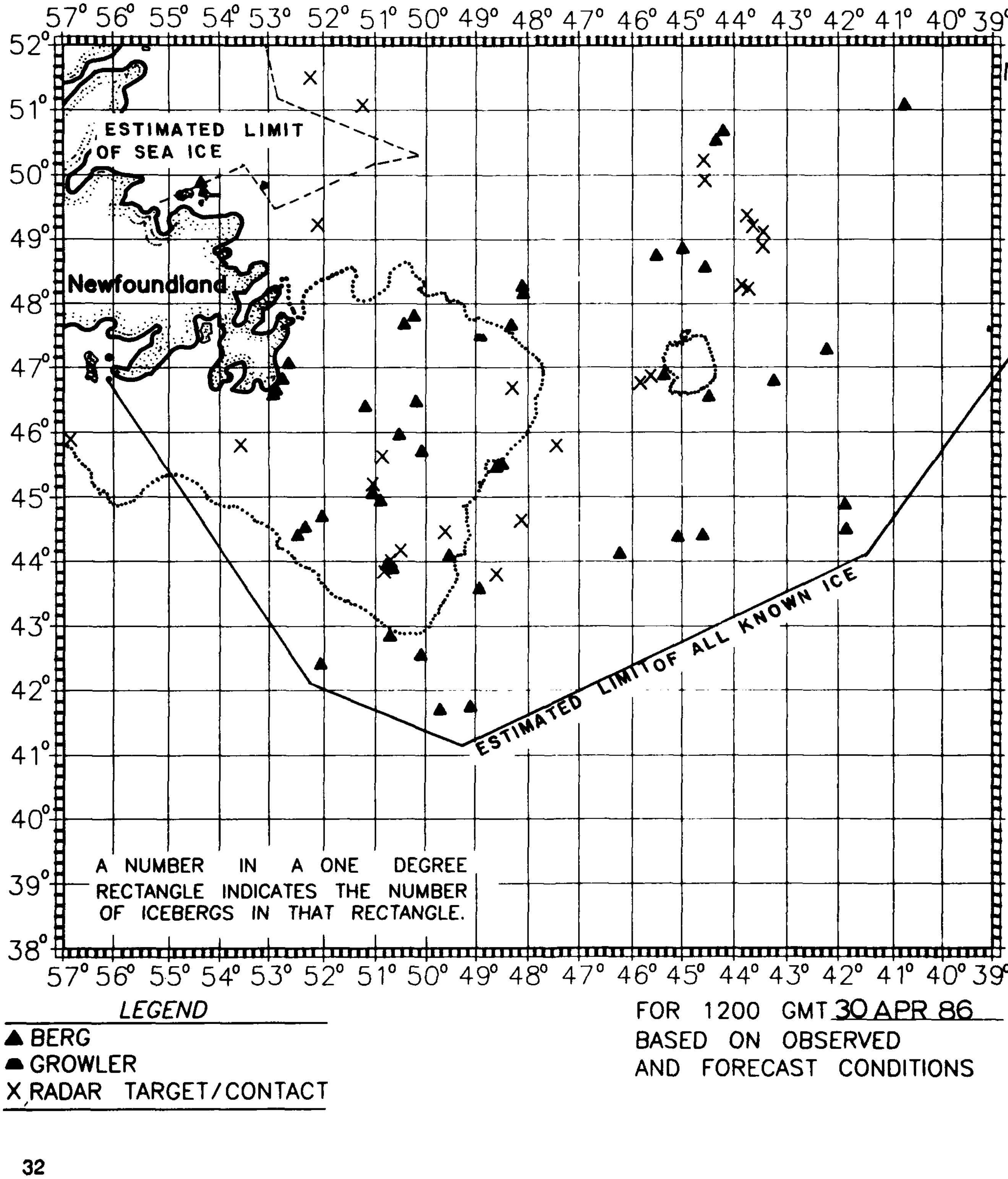


Figure 22. May 16, 1986

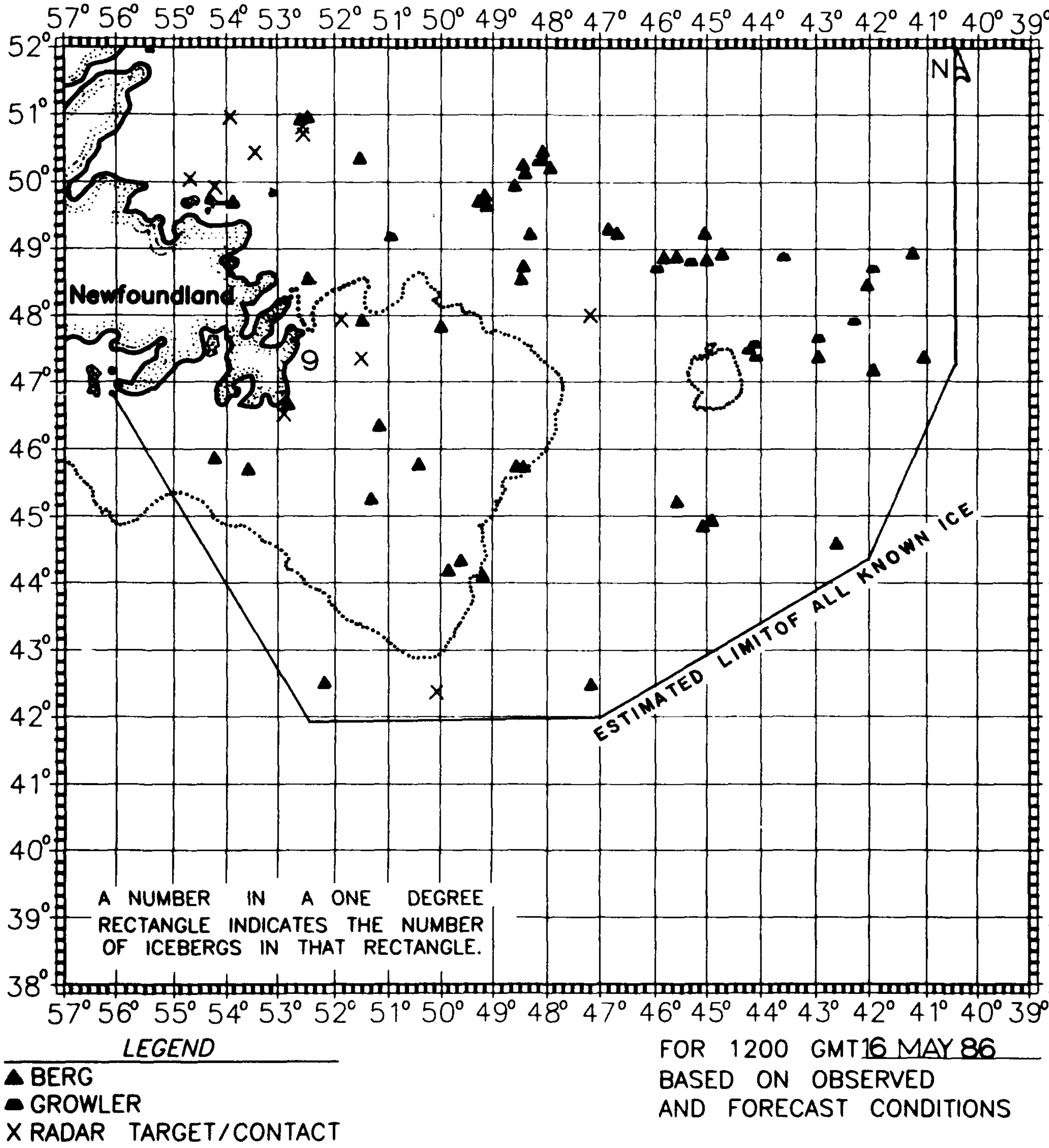


Figure 23. May 30, 1986

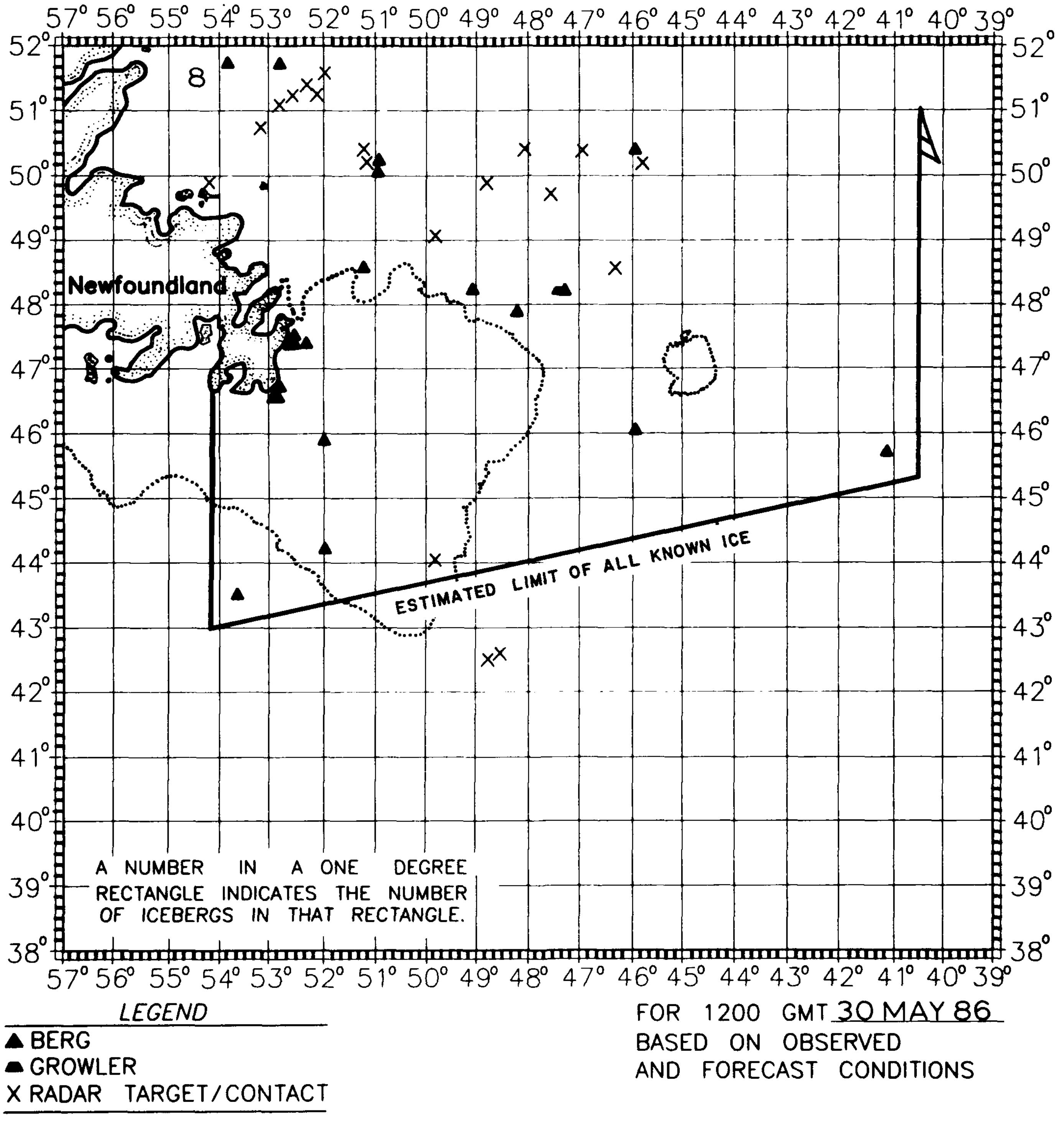


Figure 24. June 16, 1986

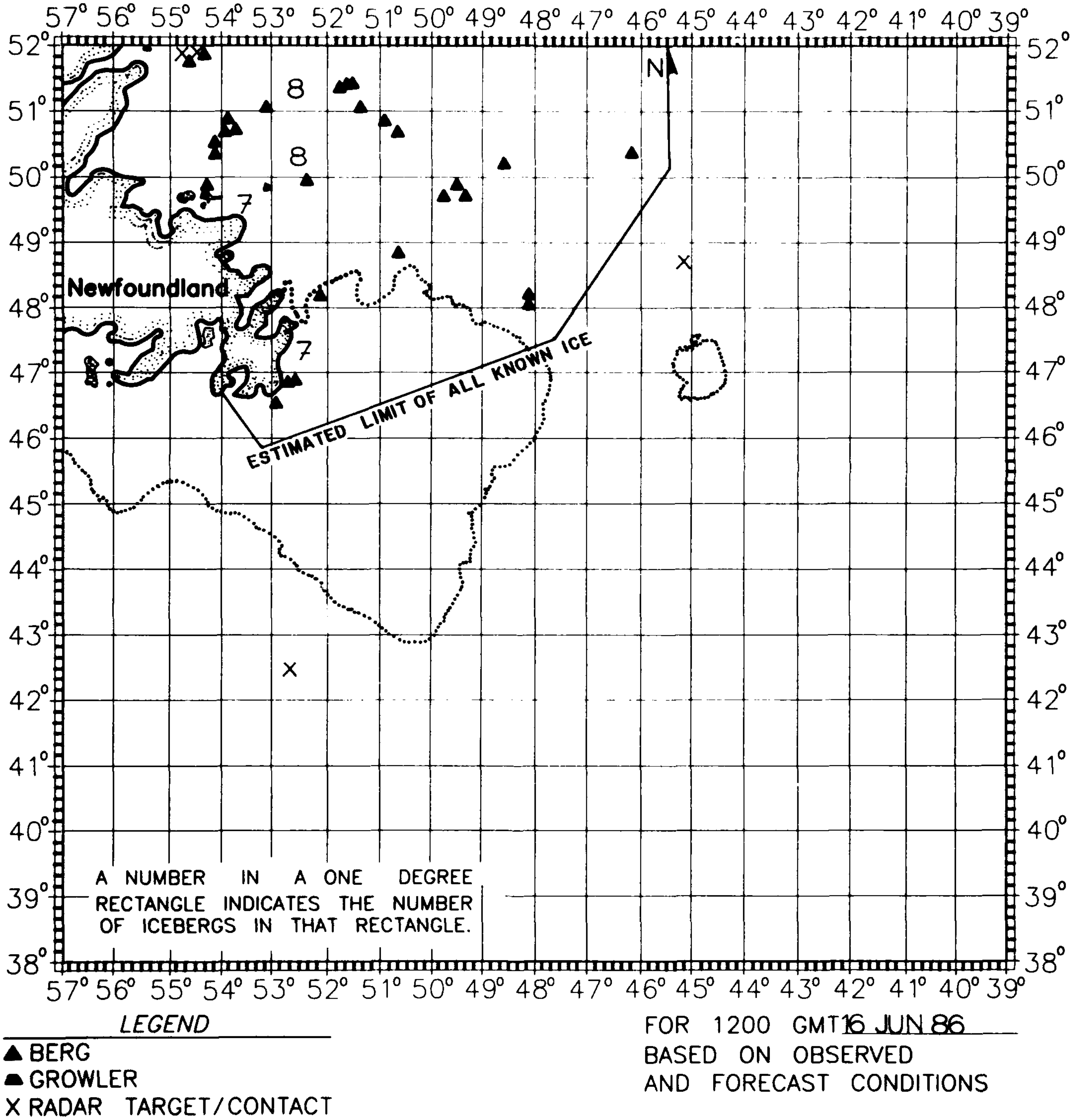


Figure 25. June 30, 1986

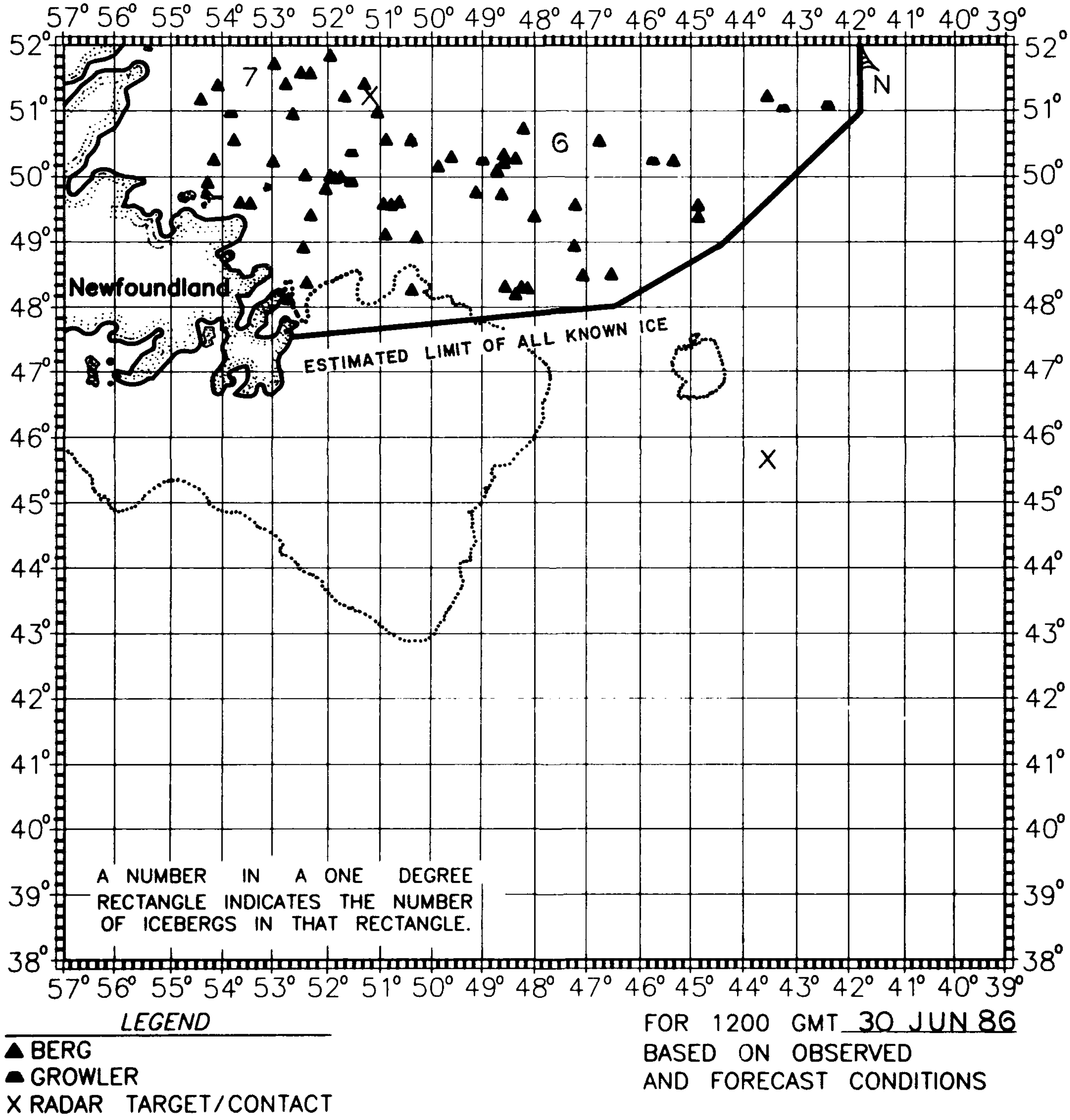
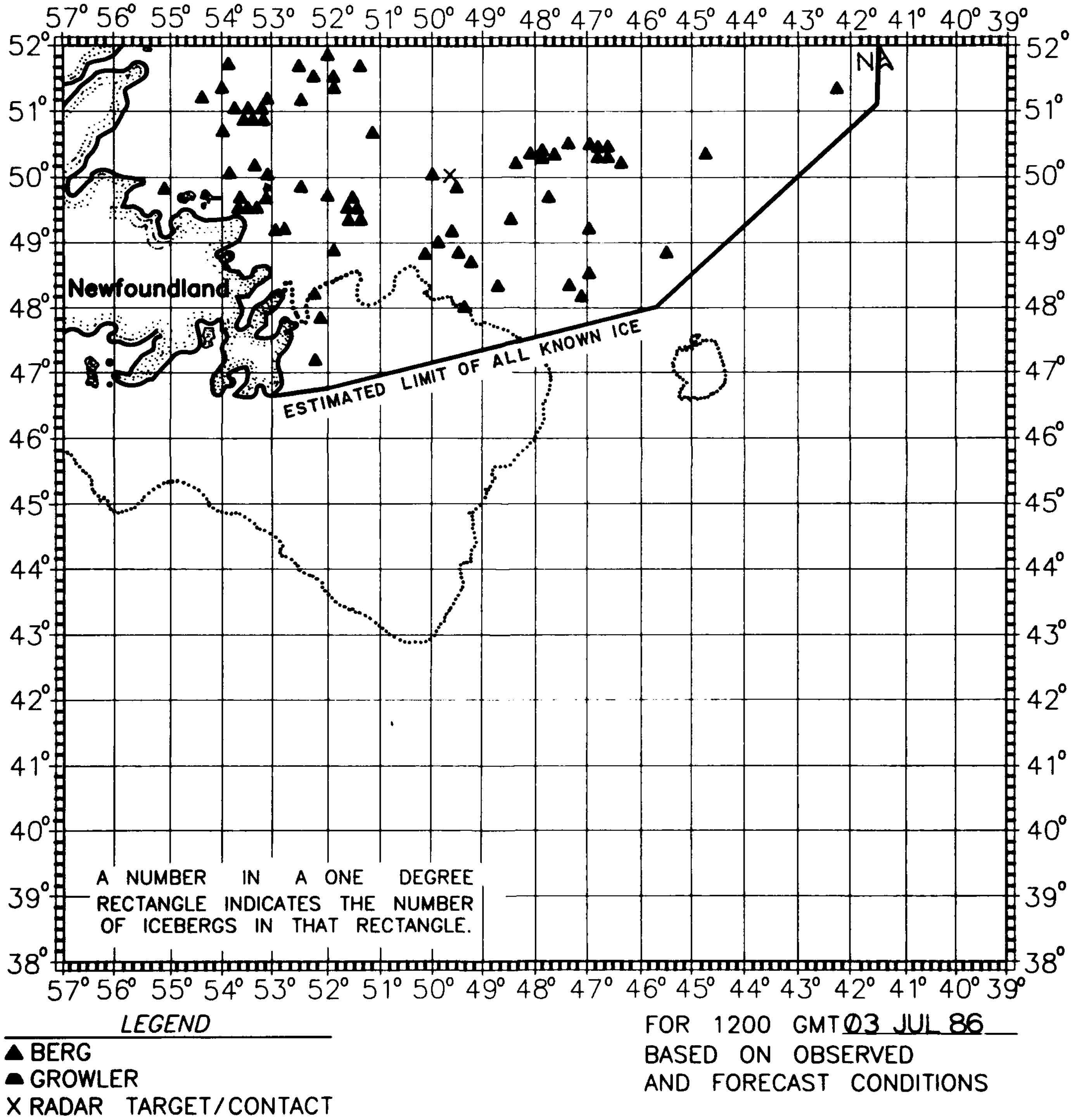


Figure 26. July 3, 1986



Discussion of Iceberg and Environmental Conditions

The number of icebergs that pass south of 48°N in the International Ice Patrol area each year is the measure by which International Ice Patrol has judged the severity of each season since 1912 (Table 1). With 204 icebergs south of 48°N, 1986 is the 49th most severe year on record, a relatively light year.

Since the number of icebergs calved each year by Greenland's glaciers is in excess of 10,000, a sufficient number of icebergs exist in Baffin Bay during any year. Therefore, annual fluctuations in the generation of Arctic icebergs is not a significant factor in the number of icebergs passing south of 48°N annually. The factors that determine the number of icebergs passing south of 48°N each season can be divided into those affecting iceberg transport (currents, winds, and sea ice) and those affecting iceberg deterioration (wave action, sea surface temperature, and sea ice).

Sea ice acts to impede the transport of icebergs by winds and currents and also protects icebergs from wave action, the major agent of iceberg deterioration. Although it slows current and wind transport of icebergs, sea ice is itself an active medium, for it is continually moving toward the ice edge where melt occurs. Therefore, icebergs in sea ice will eventually reach open water unless grounded. The melting of sea ice itself is affected by snow cover (which slows melting) and air and sea water temperatures. As sea ice melt accelerates in the spring and early summer, trapped icebergs are rapidly released and then become subject to normal transport and deterioration.

Acknowledgements

Commander, International Ice Patrol acknowledges the assistance and information provided by the Canadian Department of the Environment, the U.S. National Weather Service, the U.S. Naval Weather Service, and the U.S. Coast Guard Research and Development Center.

We extend our sincere appreciation to the staffs of the Canadian Coast Guard Radio Station St. John's, Newfoundland/VON, the Gander Weather Office, the personnel of U.S. Coast Guard Air Station Elizabeth City, and the USCGC EVERGREEN for their excellent support during the 1986 International Ice Patrol season.

It is also extremely important to recognize the efforts of the personnel of the International Ice Patrol:
CDR N.C. Edwards, Jr., Dr. D.L. Murphy, LT F. J. Williams, LT I. Anderson, LTJG N.B. Thayer, MSTCS G.F. Wright, MSTC D.A. Eichmann, MST1 M.G. Barrett, YN1 S.A. Cooper, MST1 K.O. Pelletier, MST1 R. J. Uebelacker, MST2 A.A. Anzelmo, MST2 D.A. Hutchinson, MST2 R.L. Franco, MST2 J.K. Silves, MST3 W.A. Henry, MST3 K.A. Martin, MST3 C.F. Weiller.

Appendix A
List of Participating Vessels

VESSEL NAME	FLAG	SST	ICE REPORTS
ABITIBI CONCORD	FEDERAL REPUBLIC OF GERMANY		1
ACADIAN GAIL	CANADA		1
ACHILLES	SINGAPORE		6
ACT 7	UNITED KINGDOM		3
AIME GAUDREAU	CANADA		1
AKRANES	ICELAND		1
AKTEA	EGYPT		1
ALBRIGHT	UNITED KINGDOM		1
ALRAZIQ	REPUBLIC OF LIBERIA	9	
AMBASSADOR	UNITED KINGDOM		1
AMBROSE SHEA	CANADA		6
AMERICA EXPRESS	FEDERAL REPUBLIC OF GERMANY	1	1
AMERSHAM	PANAMA		2
AMITIBICORD	FEDERAL REPUBLIC OF GERMANY		1
ANANGEL HORIZON	GREECE		1
ARC MINOS	GREECE		2
ARCTIC	CANADA		1
ARCTIC SHIKO	UNKNOWN		1
ARGO 2	PANAMA	1	
ARTHUR W. RADFORD	UNKNOWN		1
ATLANTIC SERVICE	FRANCE		1
ATLANTIC STAR	SINGAPORE		4
BADAK	LIBERIA		3
BAKAR	LIBERIA	3	
BARTLETT	CANADA		11
BARWA	LIBERIA	7	
BEAUSONGE	MAURITIUS		2
BELLE ETOILE	MAURITIUS	2	2
BHAVABHUTI	INDIA	1	1
BISCHORSTOR	PANAMA		1
BIYO MARU	JAPAN		1
BOEFJORD	PHILIPPINES		1
BONAVISTA	UNKNOWN		1
BONNY	BAHAMAS	8	3
BORIJINIBA	UNKNOWN	1	
BOWDRILL 3	CANADA		2
BOXY	SWEDEN		4
BRANT POINT	UNITED KINGDOM		4
BRISTOL MARU	JAPAN		1
BRITISH STEEL	UNITED KINGDOM		6
BUDAPESHT	SINGAPORE		1
CAMBRIDGE	PANAMA		1
CANADA MARITIME	SINGAPORE		2
CANADA MARQUIES	CANADA		1
CANADIAN EXPLORER	UNITED KINGDOM		7

VESSEL NAME	FLAG	SST	ICE REPORTS
CANMAR AMBASSADOR	CANADA		5
CANMAR (DART) EUROPE	BELGIUM		4
CANMAR VENTURE	UNITED KINGDOM		1
CANTIHOLANDIA	FEDERAL REPUBLIC OF GERMANY	1	
CAPE BALLARD	CANADA		1
CAPE NORTH	CANADA		5
CAPE RACE	UNITED KINGDOM	3	
CAPE ROGER	CANADA		3
CAPITAN CHUKACHIN	UNKNOWN		1
CARAVEL STAR	PANAMA		1
CAST CARIBOU	LIBERIA	14	7
CAST HUSKEY	UNITED KINGDOM		4
CAST MUSKOX	UNITED KINGDOM		1
CAST OTTER	UNITED KINGDOM		2
CAST POLAR BEAR	LIBERIA	9	5
CHARLOTTE CASTIAN	FEDERAL REPUBLIC OF GERMANY		1
CHEMICAL TRANSPORT	CANADA		2
CHESTNUT HILL	USA		1
CHIBA	UNITED KINGDOM		1
CHIGNECTO BAY	CANADA		3
CHIPPEWA	LIBERIA		1
COMFORT COVE	CANADA		2
CUNARD	UNKNOWN		1
DANIELA	BRAZIL		2
DANILOVGRAD	YUGOSLAVIA		2
DART ATLANTIC	UNITED KINGDOM		1
DART BRITIAN	UNITED KINGDOM		1
DONNY	SWEDEN		2
DORIS	FEDERAL REPUBLIC OF GERMANY		1
DUESSELDORE EXPRESS	FEDERAL REPUBLIC OF GERMANY		1
EASTERN SHELL	UNKNOWN		1
EASTERN UNICORN	PANAMA	1	1
ESPANA 1	FEDERAL REPUBLIC OF GERMANY	1	
EUROPE	BELGIUM		5
EVA	FRANCE	1	1
EVERGREEN	USA	15	1
FALCON	NORWAY		1
FALKNES	NORWAY		1
FARLAND	UNITED KINGDOM		1
FARNES	LIBERIA		1
FEDERAL DANUBE	BELGIUM		3
FEDERAL HURON	PANAMA	1	2
FEDERAL LAKES	USA		3
FEDERAL MAAS	BELGIUM		5
FEDERAL OTTAWA	BELGIUM		1

VESSEL NAME	FLAG	SST	ICE REPORTS
FEDERAL RHINE	LIBERIA		1
FEDERAL SCHELDE	LIBERIA	3	
FEDERAL THAMES	BELGIUM		2
FERNGOLF	LIBERIA		1
FERNWAVE	LIBERIA	1	
FINNARCTIS	UNITED KINGDOM		1
FINNFIGHTER	FINLAND		5
FINNPOLARIS	UNITED KINGDOM		2
FINNSNES	LIBERIA		1
FINNWHALE	UNKNOWN		1
FJELLNESS	PANAMA		1
FJORD MARINER	PANAMA		2
FORT VICTORIA	UNITED KINGDOM		1
GIZHIGA	USSR		1
GOLDEAN PIONEER	PHILIPPINES		1
GOLDEN GATE SUN	SINGAPORE	2	
GRENFELL	CANADA		1
GUNRUN MAERS	DENMARK	1	
HIBISCUS	MAURITIUS		1
HOLCAN ELBE	FEDERAL REPUBLIC OF GERMANY		2
HOLCAN MAAS	FEDERAL REPUBLIC OF GERMANY		2
HUDSON	CANADA		14
HUMBER ARM	LIBERIA		4
IBERITA	UNITED KINGDOM		2
IMPERIAL ACADIA	CANADA		3
IMPERIAL ST. CLAIR	CANADA		5
IVAN TEVOSYAN	UNKNOWN		1
IRVING CEDAR	UNITED KINGDOM		1
IRVING OURS POLARIS	CANADA		2
JACKMANN	CANADA		1
JADE KIM	PANAMA		2
JENNA	GERMAN DEMOCRATIC REPUBLIC		1
JOHANNA	FEDERAL REPUBLIC OF GERMANY		1
JOHN C. HELMSING	CYPRUS		2
JOKUFELL	ICELAND		1
JUGOAGEN	YUGOSLAVIA		
KAMENITZG	BULGARIA		1
KANGUK	CANADA		6
KHAIRPUR	PAKISTAN		1
KIISLA	FINLAND		1
K. OLSHANSKY	USSR		1
KRISTINA LOGOS	CANADA		1
L. ROSETTE	CANADA		4
LAKE ANINA	NORWAY		1
LAKE SHELL	CANADA		2

VESSEL NAME	FLAG	SST	ICE REPORTS
LAWRENCE H. GIANELLA	UNKNOWN	21	
LE CREDE NO. 1	CANADA		4
LENINSK	USSR		3
LEONARD J. COWLEY	UNKNOWN		5
LOK VIHAR	INDIA		1
LUCIEN PAQUIN	CANADA		2
LYRA	POLAND		1
M. W. NEAL	UNITED KINGDOM		1
MAGRITTE	BELGIUM		3
MAHONE BAY	CANADA		1
MANCHESTER CHALLENGE	UNITED KINGDOM		7
MARIA B.	UNKNOWN		2
MARIA OLDENDORFF	PANAMA	7	
MAVRO VETRANIC	INDIA	3	1
MELLA	PANAMA	5	2
MELISSA MARY	LIBERIA		2
MICHELLE C.	PANAMA	8	
MIJDRECHT	NETHERLANDS		1
MIRABELLA	NETHERLANDS ANTILLES		1
MONTCALM	FRANCE	1	1
MOSEL ORE	LIBERIA		5
MYRSINIDI	LIBERIA		4
NARWIK 2	POLAND		2
NAVIOS COURIER	LIBERIA	4	
NEDRILL	NETHERLANDS		1
NEWFOUNDLAND HAWK	CANADA		1
NORDSTAR	SINGAPORE		1
NORTH WIND	USA	71	
NORTHERN PRINCESS	UNKNOWN		1
NORTHERN SHELL	CANADA		2
NORTRANS ELMA	PANAMA	3	
OCEAN LINK	UNITED KINGDOM	3	
OFFSHORE HUNTER	UNKNOWN		2
OLYMPIC RAINBOW	GREECE		1
ONTADOC	CANADA		1
PARADISE SOUND	UNKNOWN		1
PASSAT	PANAMA		2
PAUL BUNYAN	USA		3
PAWEE	UNITED KINGDOM	2	
PEGGY	BAHAMAS	2	
PLACENTIA BAY	CANADA		5
POINT ARMUR	BAHAMAS	3	
PRINS FREDRIK HENDRIK	NETHERLANDS		1
PRINS MAURITS	NETHERLANDS		1
PRISTINA	YUGOSLAVIA		1

VESSEL NAME	FLAG	SST	ICE REPORTS
PUHOS	UNITED KINGDOM	7	3
RAINBOW HOPE	UNKNOWN		1
RANFORD	UNKNOWN		1
REED VOYAGER	PANAMA		4
ROBIN	FRANCE	1	1
SAAR PRE	LIBERIA		1
SAUNIERE	CANADA		1
SAYA	YUGOSLAVIA		1
SEA FORTH ATLANTIC	CANADA		2
SEA FORTH ISLAND	CANADA		1
SENTIS	UNITED KINGDOM		
SHOW OLYMPIA	PANAMA	5	1
SIR HUMPHREY GILBERT	CANADA		5
SIR ROBERT BOND	CANADA		21
SENHOR DOS MARANTES	PORTUGAL		1
SOUNION	CYPRUS		1
SPYROS ALEMOS	GREECE	1	
STAR	UNKNOWN		1
STEFAN BATONY	POLAND	4	4
STEPHANITOR	PANAMA		1
STOLT CASTLE	LIBERIA		1
STOLT TENACITY	LIBERIA		1
STOVE CAMPBELL	NORWAY	7	1
STUBBENHUK	FEDERAL REPUBLIC OF GERMANY		1
STUTTGART EXPRESS	FEDERAL REPUBLIC OF GERMANY		1
SUMMIT	LIBERIA	9	2
TELFAIR MARINER	LIBERIA		1
TEXACO BRAVE	CANADA		2
TOANUI	CANADA		1
TONGALA	UNITED KINGDOM		1
TRAWLER ZIDANI	UNKNOWN		1
TRINITY BAY	CANADA		1
TRONES	PANAMA		1
TUPPER	CANADA	1	1
VALCOURT	LIBERIA	3	
VARJAKKA	FINLAND		2
VASILI SURIKOV	USSR		1
VENTURA	FEDERAL REPUBLIC OF GERMANY		1
VESALIUS	BELGIUM		1
VIKING HARRIER	SINGAPORE	1	1
VIKING OSPREY	SINGAPORE	3	1
VJAZMA	USSR		1
VOLGA	UKRANIAN SSR		2
VOLNA	USSR		1
WHIDBEY ISLAND	UNKNOWN		1

VESSEL NAME	FLAG	SST	ICE REPORTS
WINNA	UNKNOWN		1
WORLD CONTAINER	PANAMA		2
YAMAHMEMARU	JAPAN	4	1
YAYAMARIA	JAPAN		1
YUKONA	CYPRUS		1
ZAMBIA	LIBERIA		8
ZEILA	UNKNOWN		1
ZIEMIA GNIEZMIESKA	POLAND		1
ZIEMIA KRAKOWSKA	POLAND		1
ZIEMIA OLSZTYNSKA	POLAND		1
ZIEMIA ZAMOJSKA	POLAND	6	
ZIM SAVANNAH	ISRAEL		1

Appendix B

TIROS Oceanographic Drifter Tracks on the Grand Banks During the 1986 International Ice Patrol Season

LT Iain Anderson, USCG

Introduction

During the 1986 International Ice Patrol season, nine TIROS Oceanographic Drifting buoys were deployed in the Ice Patrol operating region. Three of the nine drifters were used exclusively for data gathering in conjunction with the IIP-1-86 cruise and these data are discussed in Appendix C. Of the six buoys used operationally, five were deployed by HC-130 aircraft during regular ice reconnaissance flights. The sixth was deployed by USCGC EVERGREEN as part of IIP-1-86 cruise and was not recovered so that its track could be used operationally.

An oceanographic cruise was conducted using USCGC EVERGREEN (WMEC 295) from 22 April until 22 May 1986. The primary objective of the cruise was to provide surface truth data for an airborne radar study of an oceanic front south of Flemish Cap. The results of the cruise are discussed in Appendix C.

The International Ice Patrol uses drifting buoys for real-time current information for weekly updates to the historical current field used in its iceberg drift model (Summy and Anderson, 1983 and Summy, 1982). Drifters are deployed for operational use in areas of high iceberg density and in areas of high variability in the current field to improve drift prediction. All of the drifters except drifter 4547 were deployed to monitor the variability of the Labrador Current. Drifter 4547 was deployed near the end of the Ice Patrol season in the area of the highest remaining iceberg concentration.

All of the buoys deployed by Ice Patrol are three meters long and have a spar-shaped hull with a flotation collar. They are equipped with a sea surface temperature sensor, a drogue tension sensor, and a battery voltage monitor. The temperature sensor is located approximately one meter below the surface. Each drifter is deployed with a 2m by 10m window shade drogue attached to the drifter by a 50m tether. An average of nine positions per day was received from each operational drifter with position accuracy of approximately 300m (Bessis, 1981) The positions and sensor data points are evenly distributed in time except for the period between 00Z and 04Z when virtually no data are received. This null data period is due to the orbits of the NOAA series satellites.

As of 30 September 1986, no drifter remained transmitting in the Ice Patrol region (Table B-1). Two drifters (4542 and 4547) were recovered intentionally by Coast Guard cutters. Drifter 4557 was picked up by an unknown vessel. Drifter 4552 stopped transmitting 28 days after deployment. The remaining two drifters (4543 and 4549) are still drifting across the North Atlantic, providing data outside the Ice Patrol region.

All air-launched buoys deployed properly except 4552. Its parachute opened but the wooden frame holding the buoy broke apart in the air. Because of this the parachute did not cut free from the buoy after splashdown. The remainder of the air-dropped drifters deployed properly and the parachutes released from the drifter packages.

The following section describes the data from the satellite-tracked buoys used by Ice Patrol during the 1986 iceberg season. It is not intended as an exhaustive data analysis. The data are archived at the International Ice Patrol, Avery Point, Groton, CT 06340.

Buoy Trajectories

The tracks of the operational buoys are discussed below in chronological order based on the deployment date. The numbers in parenthesis following dates are year dates (numbered sequentially from 1 January through 31 December).

4543

Buoy 4543 was deployed on 26 March 1986 (85) from an HC-130 aircraft in the Flemish Pass at 46°59.3'N 47°19.6'W (Figure B-1a). After deployment, it moved southwesterly, following the bathymetry, with an average speed of 61 cm/s until it encountered an oceanic front on 30 March (89). (This front was the focus of IIP-1-86 cruise and is dis-

Table B-1. 1986 Buoy Summary

Number	Date	Deployment Method	Position	Status	No. of days in IIP Area/Total
4543	26 MAR	C-130	46°59.3'N 47°19.6'W	Still transmitting	110/188
4542a	16 APR	C-130	47°01.1'N 47°19.7'W	Recovered 3 MAY(1)	17/17
4542b	5 MAY	EVERGREEN	46°58.2'N 47°18.5'W	Recovered 17 MAY(1)	13/13
4557	12 MAY	EVERGREEN	45°10.2'N 47°18.8'W	Recovered 14 JUL(2)	63/63
4549	16 MAY	C-130	48°25.0'N 49°29.3'W	Still transmitting	52/137
4552	30 MAY	C-130	48°10.0'N 48°55.0'W	Stopped 27 JUN	28/28
4547	12 JUN	C-130	50°59.0'N 53°00.0'W	Recovered 26 AUG(3)	75/75

Notes:
(1) Recovered and /or redployed by USCGC EVERGREEN.
(2) Picked up by an unknown vessel.
(3) Recovered by USCGC NORTHWIND.

cussed in Appendix C.) It drifted in an easterly direction along the north side of the front at an average speed of 12 cm/s until 9 April (99) when the temperature increased from about 0.8°C to 2.8°C in one day. Buoy 4543 accelerated to 47 cm/s from 9 April through 19 April (109). After 19 April, it moved in a northerly direction at 31 cm/s until it became entrained in an anticyclonic (warm core) eddy north of Flemish Cap on 8 May (128). Based on the buoy trajectory, the eddy was centered near 50°N 46°W and had no substantial translation. The approximate diameter of the eddy as defined by the buoy track was 95 km. Buoy 4543 averaged 40 cm/s while completing five loops of the eddy. It departed the eddy on 25 June (175) and drifted northeasterly, passing east of 39°W (the eastern boundary of the Ice Patrol operations area) on 14 July (195). The drogue sensor indicated the drogue remained attached throughout the period described above. As of 30 September 1986, buoy 4543 was still transmitting as it moved eastward across the North Atlantic.

4542

Buoy 4542 was used twice during 1986. The two deployments are referred to as 4542(a) and 4542(b).

Buoy 4542(a) was deployed by an HC-130 on 16 April 1986 (106) in the Flemish Pass in position 47°01.1'N 47°19.7'W (Figure B-1b). It drifted south with the Labrador Current at an average speed of 32 cm/s until 25 April (115) when it encountered an oceanic front. It drifted in an easterly direction at an average speed of 63 cm/s along the front until 30 April (120). On that date, 4542(a) turned northwest, still along the front, and drifted at 46 cm/s until recovered by USCGC EVERGREEN on 3 May (123).

Buoy 4542(b) was redeployed from EVERGREEN on 5 May 1986 (125) in the Flemish Pass in position 46°58.2'N 47°18.5'W. It drifted south along the bathymetry at 37 cm/s until encountering the front again on 11 May (131). It then moved easterly along the front at an average speed of 53 cm/s until 13 May (133) when it turned north and slowed to 8 cm/s. Drifter 4542(b) was recovered by EVERGREEN on 17 May (137). The drogue remained attached to drifter 4542 throughout both deployments, and this fact was accurately reported by the drogue sensor.

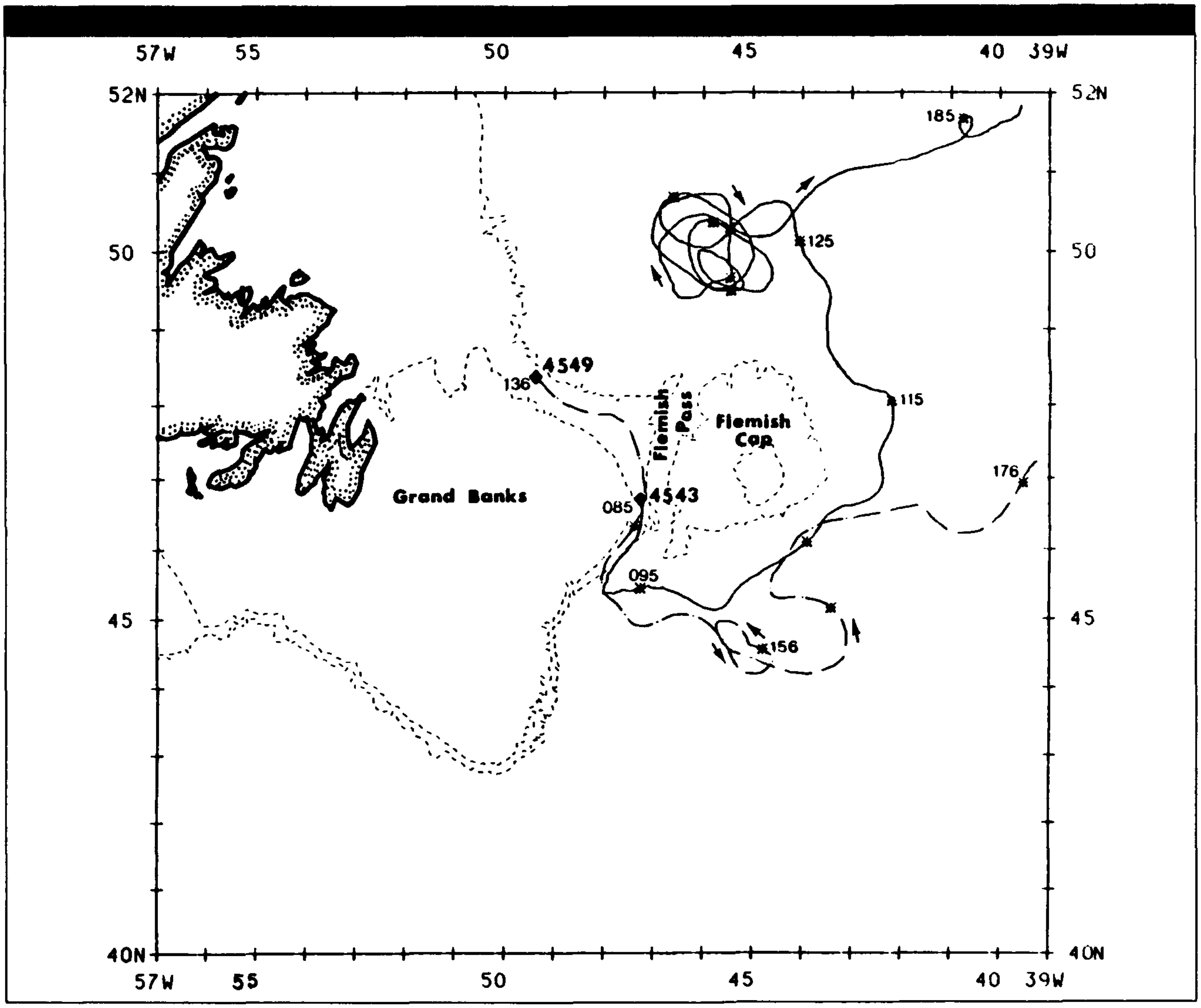


Figure B-1a Drift trajectories of buoys 4543 and 4549, marked with Julian dates.

4557

Buoy 4557 was deployed in a warm core eddy (45°10.2'N 47°18.8'W (Figure B-1b)) on 12 May 1986 (132) from USCGC EVERGREEN as part of an oceanographic study. It remained in the eddy for three revolutions as the eddy migrated to the east at about 4 km/day until 7 June (158). Based on the buoy track, the average diameter of the eddy was 70 km and within the eddy, drifter 4557 averaged 34 cm/s. Except for two short periods, the temperature reported by drifter 4557 was about 12°C while in the eddy. In the first, a 24-hour period on 25 May, the temperature decreased to about 7°C and then returned to 12°C. The drifter motion was not affected, suggesting that the cold water encountered was only a surface feature. During the second, a 48-hour period beginning on 30 May, the temperature decreased to about 6°C and then returned to 12°C. The direction of the drifter was apparently unaffected but the average speed nearly doubled, to 65 cm/s.

After leaving the warm core eddy on 7 June (158), 4557 moved eastward until 10 June (161) when it entered a cyclonic (cold core) eddy. In a 24 hour period, the temperature dropped from 12°C to 7°C. Drifter 4557 maintained its cyclonic motion until 23 June (174), completing two loops in the eddy. While in the cyclonic eddy, 4557's speed ranged from 11 cm/s to 133 cm/s, averaging 76 cm/s. Between 19 June (170) and 23 June (174), the temperature again rose to 12°C but the motion of the drifter did not change. The motion of 4557 between 23 June and 26 June (177) was very sluggish with velocities averaging 12 cm/s and inconsistent direction. On 26 June, the temperature increased

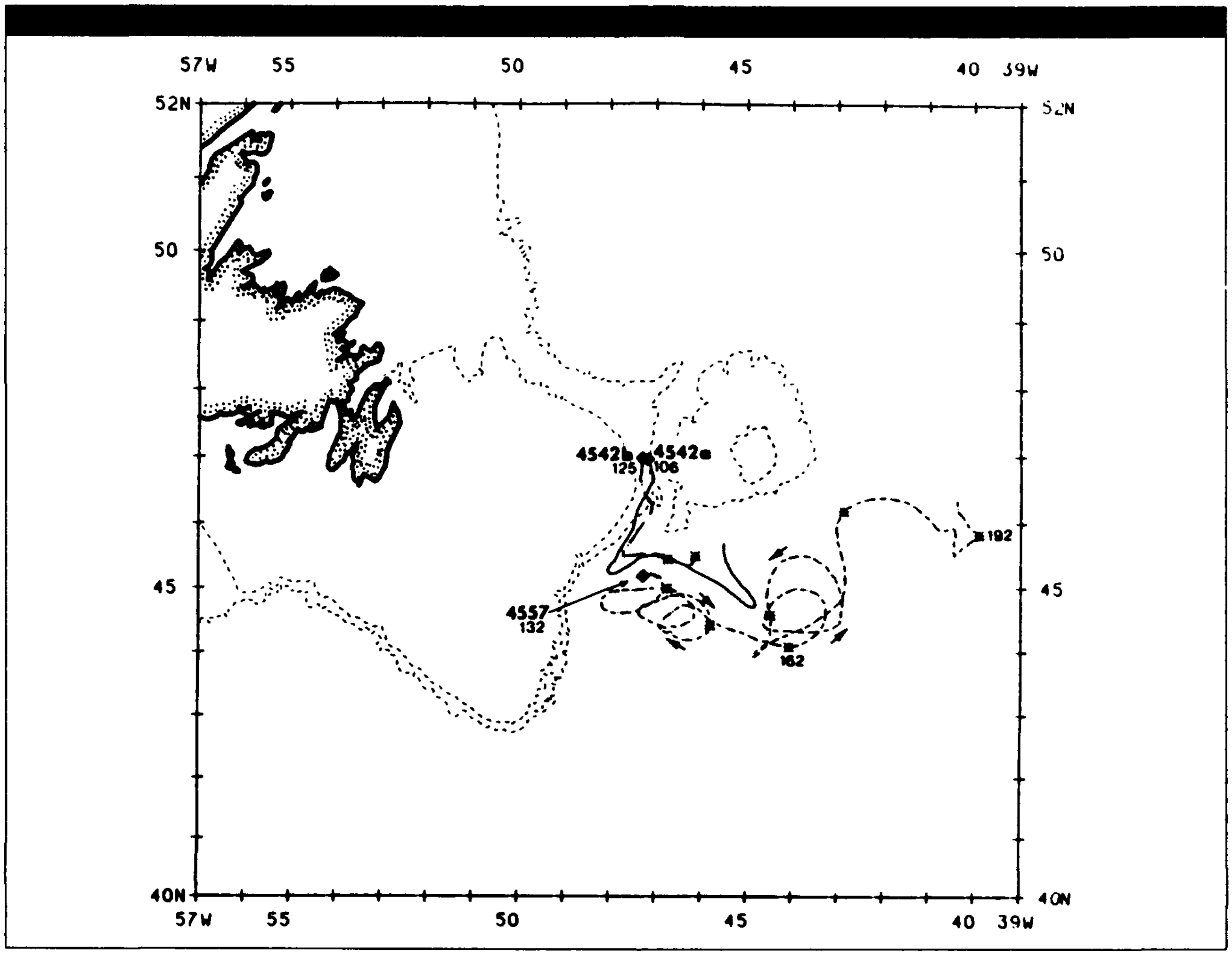


Figure B-1b Drift trajectories of buoys 4542 and 4557, marked with Julian dates.

by 2°C and 4557 was apparently caught in the North Atlantic Current and drifted towards the northeast at 45 cm/s. On 14 July (195), 4557 was picked up by an unknown vessel. The drogue sensor indicated the drogue was attached throughout its deployment.

4549

Buoy 4549 was deployed from an HC-130 north of the Grand Banks on 16 May (136) in position 48°25.0'N 49°29.3'W (Figure B-1a). It moved southward following the bathymetry at an average speed of 42 cm/s until it encountered an oceanic front on 29 May (149). The average speed of drifter 4549 increased to 65 cm/s as it travelled along the front. On 4 June (155), drifter 4549 began a small cyclonic loop. The average speed of drifter 4549 during the loop was 31 cm/s. On 13 June (164), it accelerated to an average of 96 cm/s and began a large cyclonic loop. This motion continued until 16 June (167). There was an increase from 7°C to 9°C when the motion stopped. The large cyclonic loop coincided temporally and spatially with the cyclonic eddy observed along the track of drifter 4557. Drifter 4549 moved to the north at an average speed of 30 cm/s until 19 June (170). It then accelerated to an average speed of 74 cm/s and drifted northeasterly, departing the Ice Patrol region on 27 June (178). The drogue sensor indicated the drogue was attached throughout its drift in the Ice Patrol region. As of 30 September 1986, the buoy was still transmitting.

4552

Buoy 4552 was deployed from an HC-130 north of the Grand Banks on 30 May 1986 (150) in position 48°10.0'N 48°55.0'W (Figure B-1c). It drifted south with the Labrador Current approximately following the bathymetry at an average speed of 40 cm/s until 15 June (166). It then nearly reversed direction and drifted in a northerly direction at about 25 cm/s until 27 June (178). No data were received after 27 June. There is no evidence in the data to suggest the reversal of direction was caused by the buoy being picked up by a vessel. The temperature sensor did not provide reliable data throughout the deployment. The drogue sensor indicated the drogue was attached throughout period

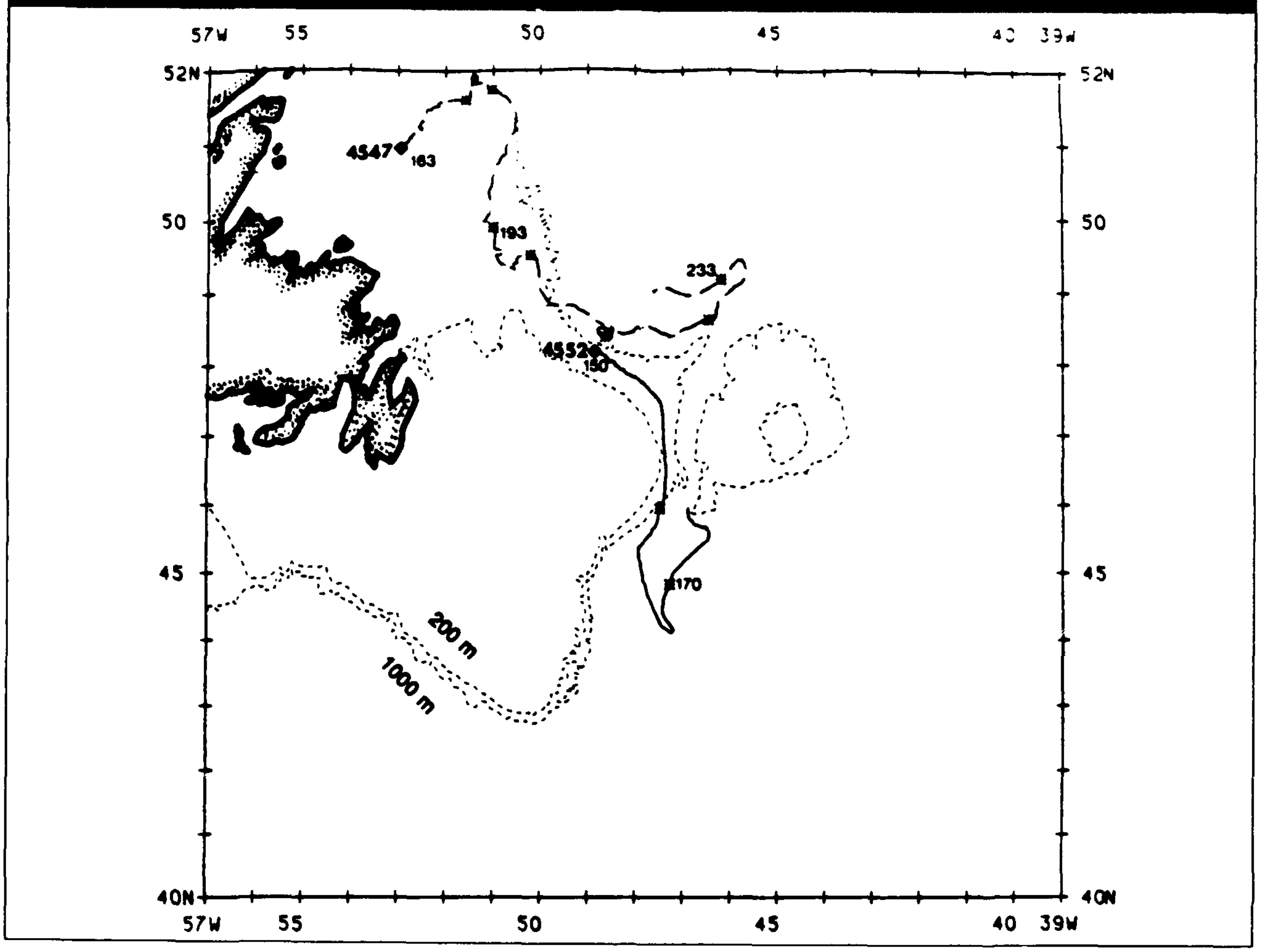


Figure B-1c Drift trajectories of buoys 4547 and 4552, marked with Julian dates.

described above. The fact that the parachute did not cut free after the buoy entered the water means that the buoy also had a near-surface parachute drogue. It is likely that the parachute wrapped around the buoy hull as happened with a 1985 buoy (Anderson, 1985). Although the track of 4552 should be viewed with caution, the fact that the parachute remained attached to the buoy is probably not an important factor.

4547

Buoy 4547 was deployed from an HC-130 on 12 June 1986 (163) in the northwestern section of the Ice Patrol region in position 50°59.0'N 53°00.0'W (Figure B-1c). After its deployment, 4547 drifted northeast at 16 cm/s until 1 July (182). On 1 July, it moved south then east with the Labrador Current until about 9 August (221). On this date, the temperature increased from about 9°C to 11°C and drifter 4557 moved northeast and then southwest at 21 cm/s until its recovery by USCGC NORTHWIND on 26 August (238).

The drogue sensor indicated the drogue became disconnected on the day after its deployment. When the buoy was recovered by NORTHWIND on 26 August 1986 (238) only about 10 meters of the tether still attached to the drifter. Inspection of the tether after recovery indicated the tether may have been cut. The prolonged low and inconsistent direction of the drift indicated early drogue loss during the deployment. This was another case where the drogue sensor reliably reported the drogue status.

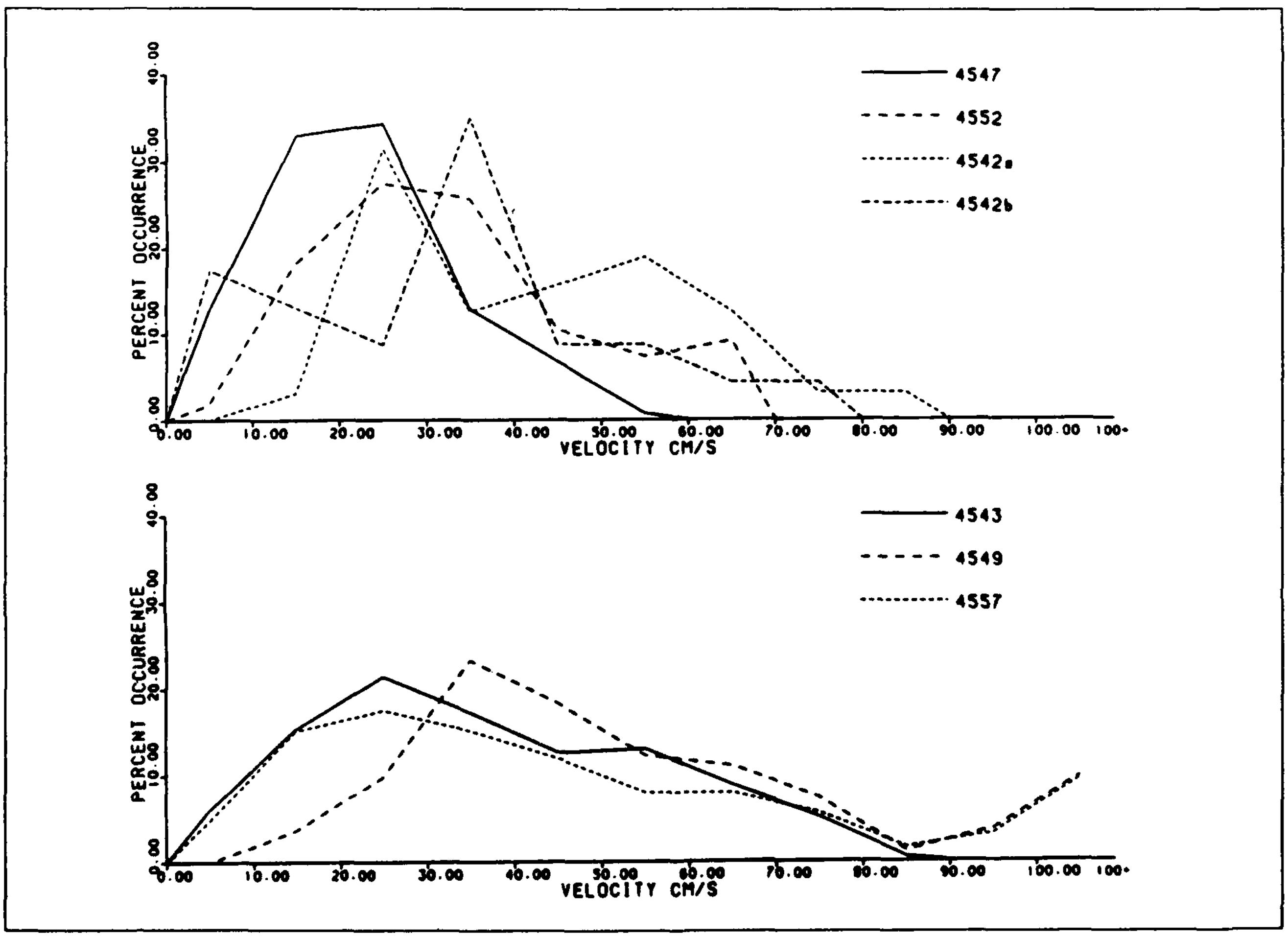
Discussion

The tracks from this year's drifters illustrate the current variability of the Ice Patrol region. The presense of the oceanic front south of the Flemish Cap greatly influenced the movement of all drifters coming through Flemish Pass. In past years, drifters moving south through Flemish Pass have gone as far south as 42°N (Anderson 1984 and 1985). This year the farthest south a drifter travelled was about 44°N (4552). This difference can be attributed directly to the front.

Buoy 4543 entered an anticyclonic eddy north of Flemish Cap. Eddies in this location have been observed in previous years (Anderson 1983 and 1985). This eddy and the front south of Flemish Cap were dominant sources of departure from the Ice Patrol normal current field during the 1986 season.

The velocity distributions of the majority of this year's drifters are very similar except for the peaks at the high velocity end (greater than 100 cm/s) of the distribution for buoys 4557 and 4549 (Figure B-2). Drifter 4549's high velocity peak was the result of its entrainment in the North Atlantic Current. The high peak of drifter 4557 coincided with the time it spent in a cyclonic eddy. The main peak of the distribution of drifter 4547 is shifted to the left towards a lower speed than the others. This shift in the peak coincide with the loss of the drogue from drifter 4547.

Figure B-2 Frequency distribution of buoy drift velocities, by percent.



Conclusion

Ice Patrol has now been using satellite-tracked buoys for 5 years to provide near real-time current data for its iceberg drift prediction model. This year is a good example of the importance of this near real time input. Without weekly drifter data input, Ice Patrol would have been using historical mean currents to predict the motion of icebergs. Using historical currents, icebergs in the Labrador Current would have been drifted south to 43°N. After modification by drifter data to the current field, icebergs in the Labrador Current were drifted south to only 45°N. The lack of drifter data could have resulted in a 190 km drift error.

The drogue sensor appears to be providing more reliable data than in the past. All five recovered buoys (including those used exclusively for the cruise), verified the drogue sensor data, with four attached and one disconnected drogue.

Ice Patrol plans to continue using drifting buoys for near real-time current data to update the historical current field. In areas of high current variability, real-time data are essential to accurate drift prediction.

Acknowledgements

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References

Anderson, I., 1983. Oceanographic Conditions on the Grand Banks During the 1983 Ice Patrol Season. Appendix B, Report of the International Ice Patrol Service in the North Atlantic. Bulletin No. 69, CG-188-38, U. S. Coast Guard, Washington, DC 20593-7399, 73 pp.

Anderson, I., 1984. Oceanographic Conditions on the Grand Banks During the 1984 Ice Patrol Season. Appendix B, Report of the International Ice Patrol Service in the North Atlantic. Bulletin No. 70, CG-188-39. U. S. Coast Guard, Washington, D.C. 20593-7399, 74 pp.

Anderson, I., 1985. Oceanographic Conditions on the Grand Banks During the 1985 Ice Patrol Season. Appendix C, Report of the International Ice Patrol Service in the North Atlantic. Bulletin No. 71, CG-188-40. U. S. Coast Guard, Washington, D.C. 20593-7399, 90 pp.

Bessis, J. L., 1981. Operational Data Collection and Platform Location by Satellite. Remote Sensing of Environment, Vol II: p 93-111.

Summy, A.D., 1982. Oceanographic Conditions on the Grand Banks During the 1982 Ice Patrol Season. Appendix B, Report of the International Ice Patrol Service in the North Atlantic. Bulletin No. 68, CG-188-37. U. S. Coast Guard, Washington, D.C. 20593-7399, 35 pp.

Summy, A.D. and I. Anderson, 1983. Operational Uses of TIROS Oceanographic Drifters by International Ice Patrol (1978 - 1982). Proceedings: 1983 Symposium on Buoy Technology, National Data Buoy Center, NSTL Station, MS 39529, pp. 246-250.

Appendix C

Observations of an Oceanic Front South of Flemish Pass

Donald L. Murphy
LT Iain Anderson
LTJG Neal B. Thayer

Introduction

In April and May 1986 International Ice Patrol (IIP) conducted a study east of the Grand Banks of Newfoundland in which airborne radar imagery of the sea surface was compared with surface-truth data. Sea surface roughness was mapped using a real aperture, X-Band, Side Looking Airborne Radar (SLAR) aboard an HC-130 aircraft; surface-truth measurements consisted of hydrographic measurements made from USCGC EVERGREEN (WMEC 295) and the trajectories of satellite-tracked drifting buoys.

The primary goal of the experiment was to determine how well and how reliably the IIP SLAR could detect water-mass boundries. A knowledge of the location of the major boundries in the IIP operations area (40°-50°N, 39°-57°W) is useful in predicting the motion of icebergs, an important part of IIP's responsibility.

The study focused on a warm core eddy spawned from, and interacting with the North Atlantic Current (NAC). No attempt is made to describe the dynamics of the eddy because the data are insufficient for such an effort. Indeed, neither the remotely-sensed data nor the hydrographic data define the eddy boundries completely and unambiguously. Only from the drifting buoy data is it clear that the feature is an eddy. The treatment of the oceanographic data is undertaken solely to help understand the SLAR imagery.

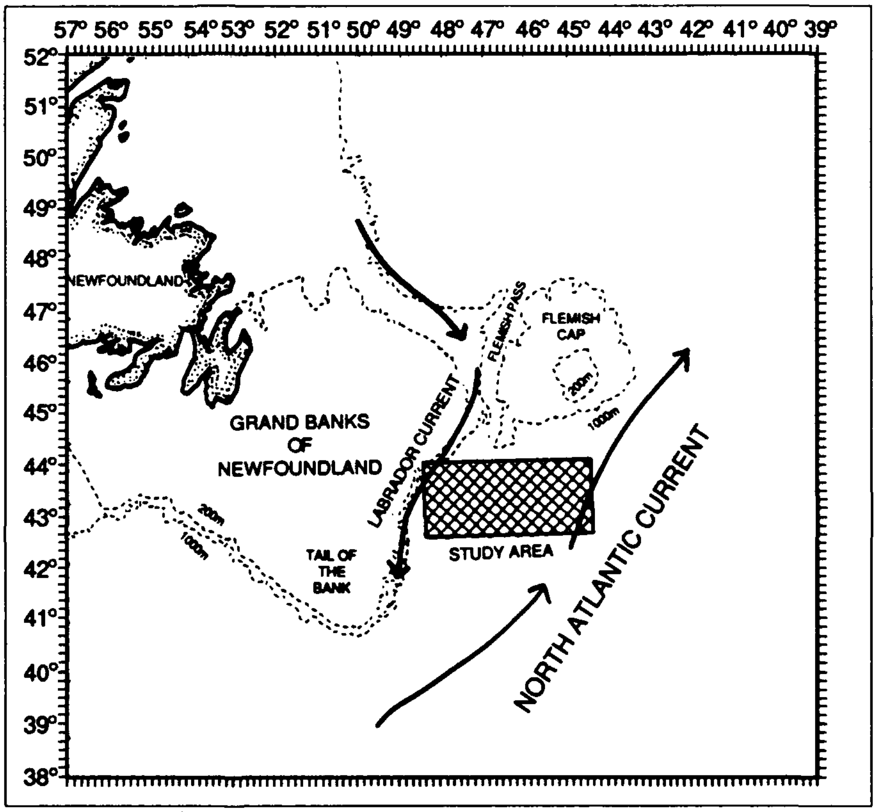
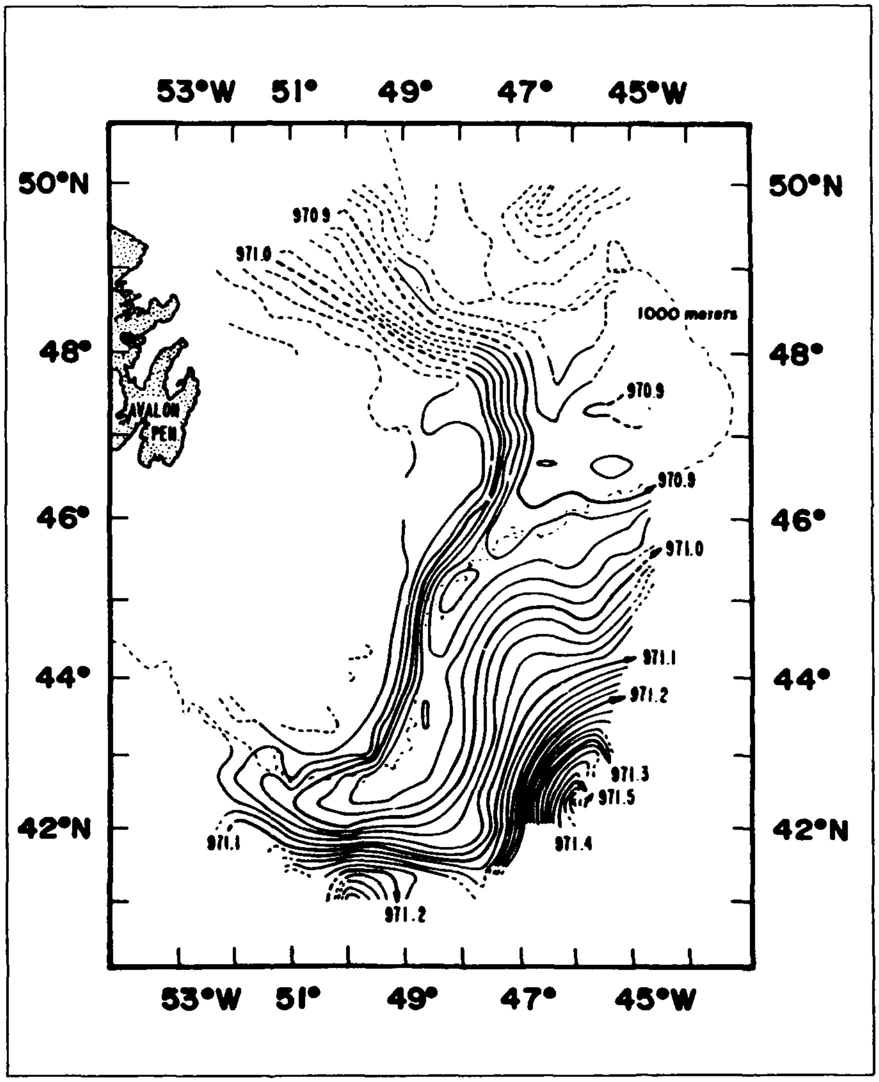


Figure C-1 Schematic of the major current systems near the Grand Banks of Newfoundland. The study area is shown by the shaded rectangle.

Background

Circulation in the North Atlantic Ocean east of the Grand Banks of Newfoundland is dominated by two major currents (Figure C-1): the southward-flowing, cold and relatively fresh (<2°C and <34.3 ppt) Labrador Current (LC) and the northeastward-flowing warm and more saline (>12°C and >35.5 ppt) NAC. The mean dynamic height field is reasonably well mapped, due in large part to the efforts of IIP, which conducted routine hydrographic surveys of the region from 1934 to 1978, excepting the years of World War II. From these data, maps of monthly mean dynamic height relative to the 1000 dbar level for April through June were developed by Soule (1964) and later updated by Scobie and Schultz (1976). Figure C-2, the mean dynamic topography for April, shows the narrow LC following along the eastern edge of the Grand Banks from Flemish Pass to the Tail of the Bank. The other months, May and June, show no

Figure C-2 Average dynamic topography for the month of April (from Scoble and Schultz, 1976).



substantial departure from this distribution. Recognizing these similarities, IIP, in 1979, combined the monthly mean hydrographic fields and computed a single mean current field (Murray, 1979) for use in IIP's numerical iceberg drift model.

While the monthly mean dynamic topography represents the main features of the circulation, the averaging smooths out variations that may affect the circulation. For example, trajectories of satellite-tracked drifting buoys released in the LC (Anderson, 1983 and Anderson, 1984) suggest a much more complex flow pattern than the mean hydrography depicts. Figure C-3 summarizes the drift tracks of 17 buoys, deployed by IIP over a 10-year period (1976-1986), that passed through the study area. Although the tracks show the LC clearly, the most striking feature of the plot is the variability in the flow field. A further indication of variability in the area is shown by the map of standard deviation of dynamic height of the individual hydrographic surveys from the April mean (Figure C-4). The pattern of fluctuations in the standard deviation suggests that meanders and eddies of the NAC are major features, particularly in the eastern and southern areas where the standard deviation reaches 15 dyn-cm.

Little is known about the sizes and frequencies of NAC meanders or eddies in the study area, primarily because fog and clouds frequently prevent mapping of the ocean's features by satellite infrared (IR) imagery. Using the sparse IR data available, Williams (1985) studied the eddy population east of the Grand Banks. He found that eddies are frequently seen near the Newfoundland Seamounts and Ridge. He suggested that eddy generation is caused by the rapid changes in bottom topography, but there were insufficient data to form a complete history of an eddy.

Although IR mapping is limited by fog and clouds, satellite and airborne imaging radars, particularly the synthetic aperture radar (SAR) carried aboard SEASAT, are capable of all-weather detection of oceanic features such as fronts and internal waves (Fu and Holt, 1982; Hayes,1981). Using

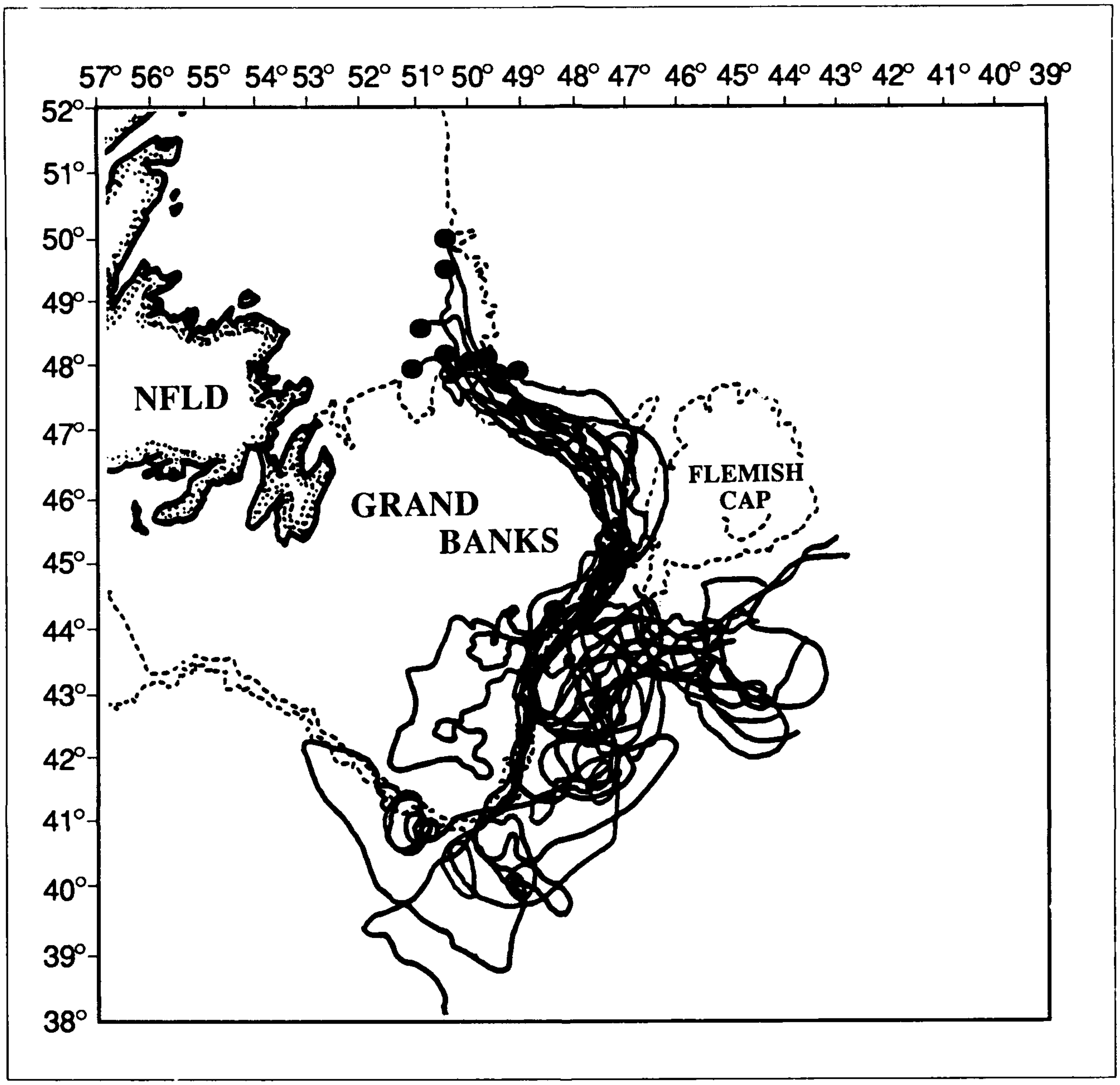


Figure C-3 Trajectories of 17 satellite-tracked buoys deployed by International Ice Patrol. The dots mark the launch positions.

SEASAT SAR data and a previous version of the IIP SLAR, LaViolette (1983) examined the ability of imaging radars to map oceanic features near the Grand Banks. He demonstrated that SLAR and SEASAT SAR showed similar features and that both radars could detect thermal fronts seen in the infrared imagery. He found, however, that in some cases the radar-defined fronts were not as sharp as those shown in the IR images. He recommended that since satellite SAR is currently unavailable and few aircraft-borne SAR's exist, SLAR-equipped aircraft should be used to improve the understanding of ocean processes.

Imaging radars map the sea-surface roughness through Bragg scattering (Robinson,1985), which for the 3-cm wavelength and incidence angles of the IIP SLAR, results in a sensitivity to ocean waves approximately 2-cm long. As a result, the IIP SLAR imagery of the ocean is essentially a map of the distribution of these 2 cm-long waves; the SEASAT SAR was sensitive to 30-cm wavelengths (Vesecky and Stewart, 1982). On both radars, differences in surface roughness are indicated on the

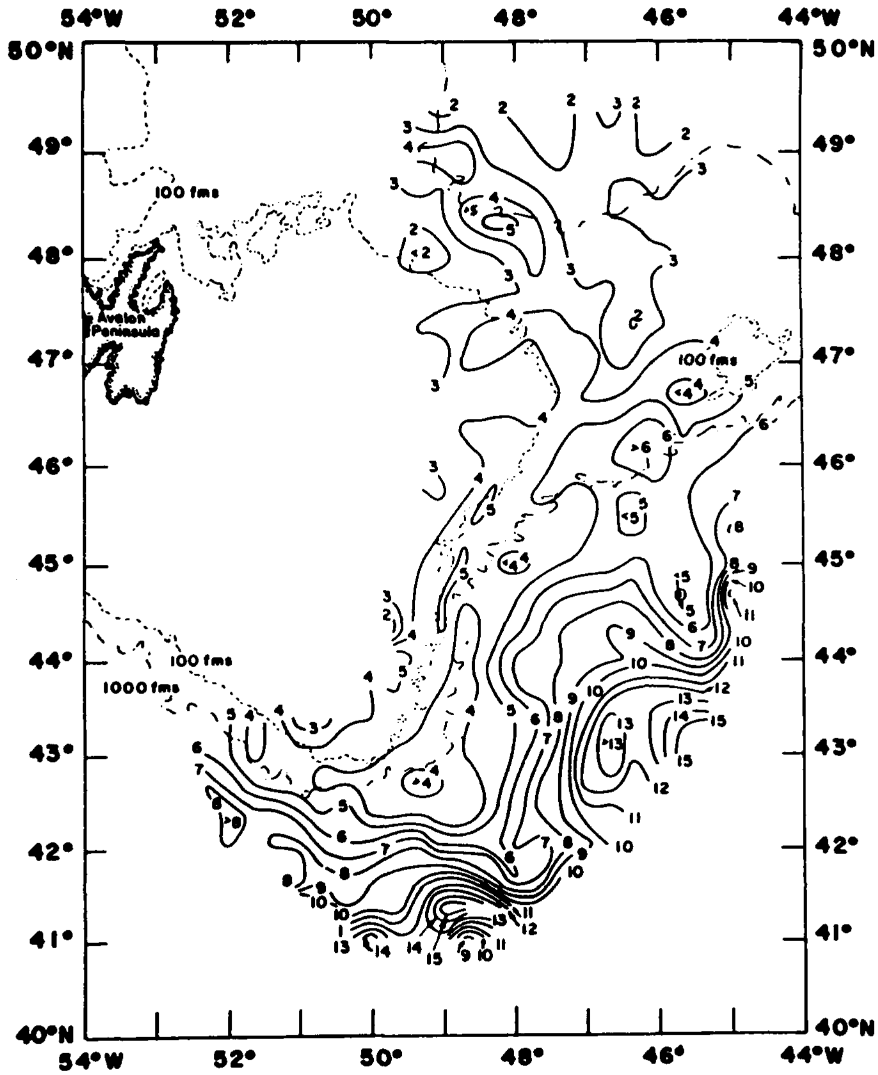


Figure C-4 Field of standard deviation of dynamic height of the individual surveys from the April normal. Contour interval is 1 dyn-cm (from Scoble and Schultz, 1976).

radar image as tonal changes. Thus, there are light and dark areas on the images that correspond to differences in the reflected radar energy.

Interpretation of the images requires an understanding of how wind stress, current gradients, etc. modulate short gravity waves on the ocean surface; but, our understanding is poor. Lichy *et al.* (1981), who tracked a warm core ring using SEASAT SAR data, found that within the warm water there was a more intense radar return than from the surrounding area.

This paper describes the results of a study of the circulation east of the Grand Banks of Newfoundland. Its goals were to collect surface-truth data for comparison of the remotely-sensed SLAR data and to investigate the effects of NAC meanders and eddies on the flow of the Labrador Current. Our intent was to locate a front using SLAR, examine the water property distribution and dynamics in the vicinity of the front with the ship, and compare the two. IIP's long-term goal is to use remote-sensing techniques to aid in iceberg movement prediction. IR imagery shows little promise near the Grand Banks because of clouds, but much can be learned from SLAR imagery. That information will help interpret future satellite SAR data and the occassional IR image.

Observational Program

Remote Sensing

SLAR imagery guided the hydrographic sampling program. The IIP SLAR is an X-band (3-cm wavelength), real-aperture radar that produces a continuous 9-inch (23 cm) analog (negative) image on a dry-process film. Because the IIP SLAR provides a negative image, areas of intense radar backscatter appear dark on the film. These dark areas mark regions where the sea surface is rough with 2-cm waves.

The aircraft, when flown at 8000 ft (2438 m), maps a 50 km wide swath on each side of the aircraft with a blind spot ~5 km wide directly under the aircraft (Figure C-5). Both of the antennas are vertically polarized. Navigational information from the HC-130's inertial navigation system (INS) is printed directly on the film.

Four aerial surveys, at approximately one-week intervals, mapped the features in the study area. The first survey (26 April 1986) covered 127,000 sq km and identified a site to conduct the hydrographic study. The three subsequent flights (2, 9, and 17 May 1986) each mapped 56,000 sq km with overlapping coverage.

On the last day of the experiment, the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA 9 satellite provided the only usable IR image of the area.

Hydrography

Hydrographic sampling was divided into two phases. In the first, 26 April to 3 May, EVERGREEN occupied 68 stations in a 18x26 km grid. At each station water temperature and salinity profiles of the upper 1000 m of the water column were made using an internally-recording CTD. The station pattern was based on inflight analyses of SLAR data. After reprovisioning, EVERGREEN returned to the study area for the second phase to repeat a similar pattern, but a winch failure after 28 CTD stations resulted in continuing the survey using only XBT's.

Over the ranges encountered in the study, the Neil Brown Internally-Recording CTD, has an accuracy of 0.01°C, 0.01 mmho and 0.5% of full scale in pressure up to 1000 dbar. Data were sampled at 5Hz, which for the 50m/min lowering rate resulted in conductivity, temperature and pressure data being collected every 0.2 dbar. Five scans of C,T, and P were averaged and recorded internally at approximately one dbar intervals. Salinity was computed using an algorithm based on Fofonoff (1985).

The primary method of navigation was LORAN-C, but when satellite-tracked buoys were aboard, their satellite-derived positions were also used to fix the ship's position.

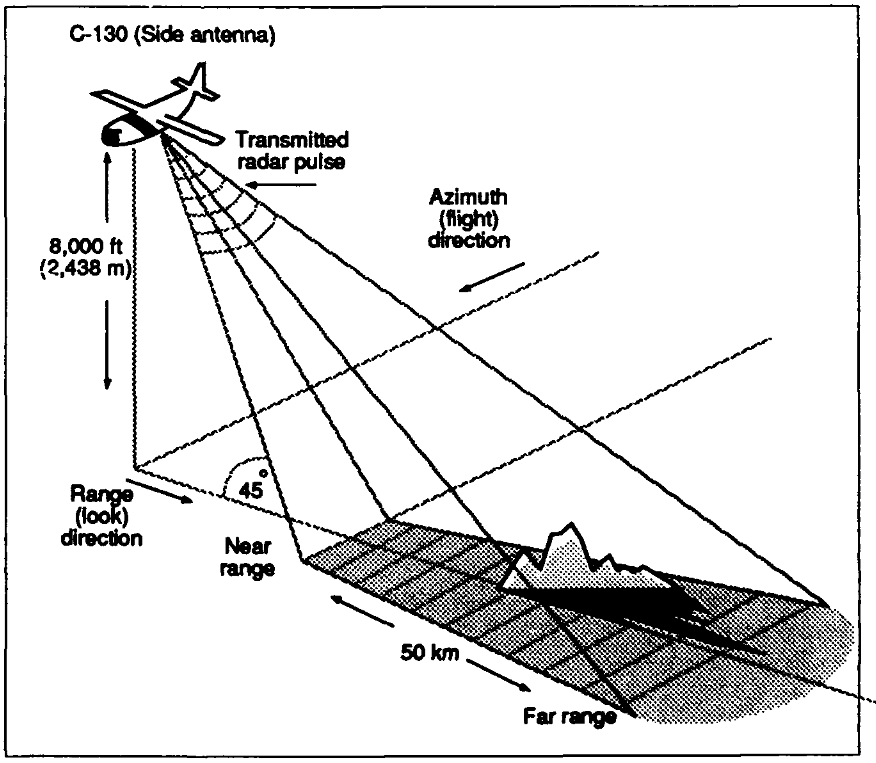


Figure C-5 Geometry of the International Ice Patrol Side-looking airborne radar (SLAR). Only one side is shown; the radar transmits and receives on both sides of the aircraft.

Drifting Buoys

In both phases, four satellite-tracked drifting buoys, each with a 2m x 10m window-shade drogue centered at 58m, were used to measure the currents. Tracked by System ARGOS, they provided 8-10 fixes (unevenly spaced in time) each day with a position accuracy of approximately 300m. The ARGOS system is described in detail by Bessis (1981). In addition to position, each buoy measured sea surface temperature at a depth of approximately 1m. All of the recovered buoys still had their drogues attached.

In the first phase, one buoy was deployed from an aircraft in the Labrador Current in Flemish Pass (47°N 47°20'W) and three were deployed by ship along the first hydrographic line (48°W). All four buoys were recovered after completion of the surveys.

As part of the second phase, EVERGREEN deployed a buoy in the Labrador Current in Flemish Pass (47°N 47°18'W) enroute to port. The buoy drifted into the study area at approximately the same time that the second hydrographic survey began. Three buoys were deployed during the surveys and before returning to port, three of the four buoys were recovered. The remaining buoy was left in the eddy. According to the drogue sensor on the buoy left in the eddy, its drogue remained in place until 7 July 1986.

Results

This section is divided into two parts. The first describes the SLAR imagery, with emphasis on the similarities and differences among the four surveys. Because some of the features on the SLAR film are difficult to reproduce photographically, the data are presented primarily in the form of digitized interpretations of the images. The second section compares the imagery with oceanic data that are derived from the hydrographic surveys and buoy tracks.

SLAR

Figure C-6, a photomosaic of the 26 April SLAR survey, shows what we interpret as the NAC, appearing as a dark region along the southern and eastern edge of the image. This is a negative image, thus the dark area represents high radar return. The area of the hydrographic study, enclosed by a box, is dominated by a sharply defined front that tends in the east-west direction. It appears to be the northern edge of a NAC meander or a newly-formed eddy that is interacting with the NAC. The SLAR imagery recorded changes in the shape and location of this feature over the subsequent three weeks (Figure C-7). In the following discussions this feature will be referred to as an eddy although the SLAR imagery is inconclusive. In no case was it possible to define all of the eddy boundaries because portions could not be located with certainty. In the cases when overlapping imagery permitted two determinations of sections of the eddy boundary , the positions agreed to about 5 km.

Although the tone of the images varied from survey to survey, the feature mapped in Figure C-7 was always characterized by greater radar return than the surrounding water. This is similar to the finding of Lichy *et al.* (1981), who found that within a warm core ring there was a more intense radar return than from the surrounding area; however, the differences were not as great as in the present SLAR data. Lichy *et al.* (1981) also

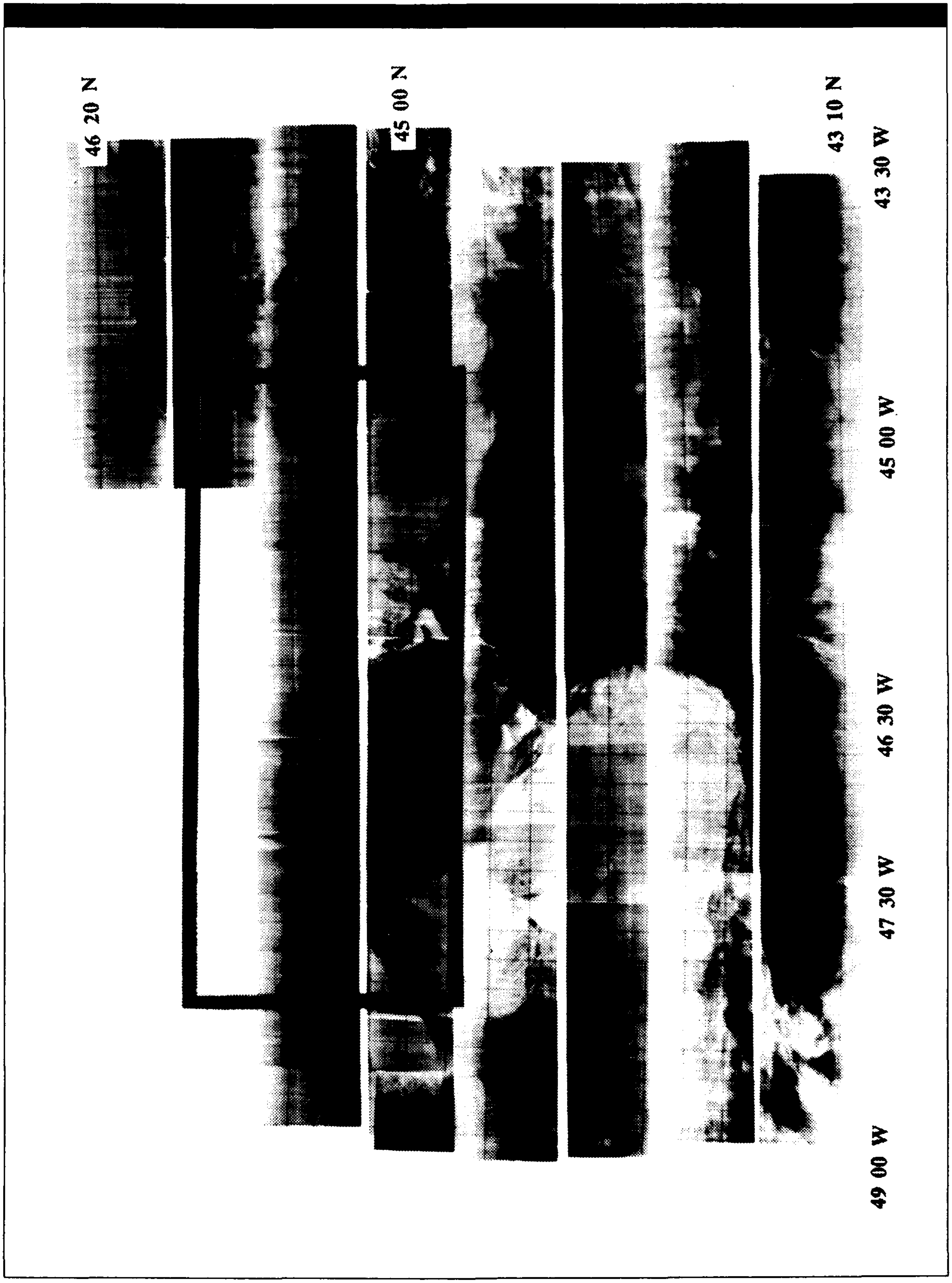
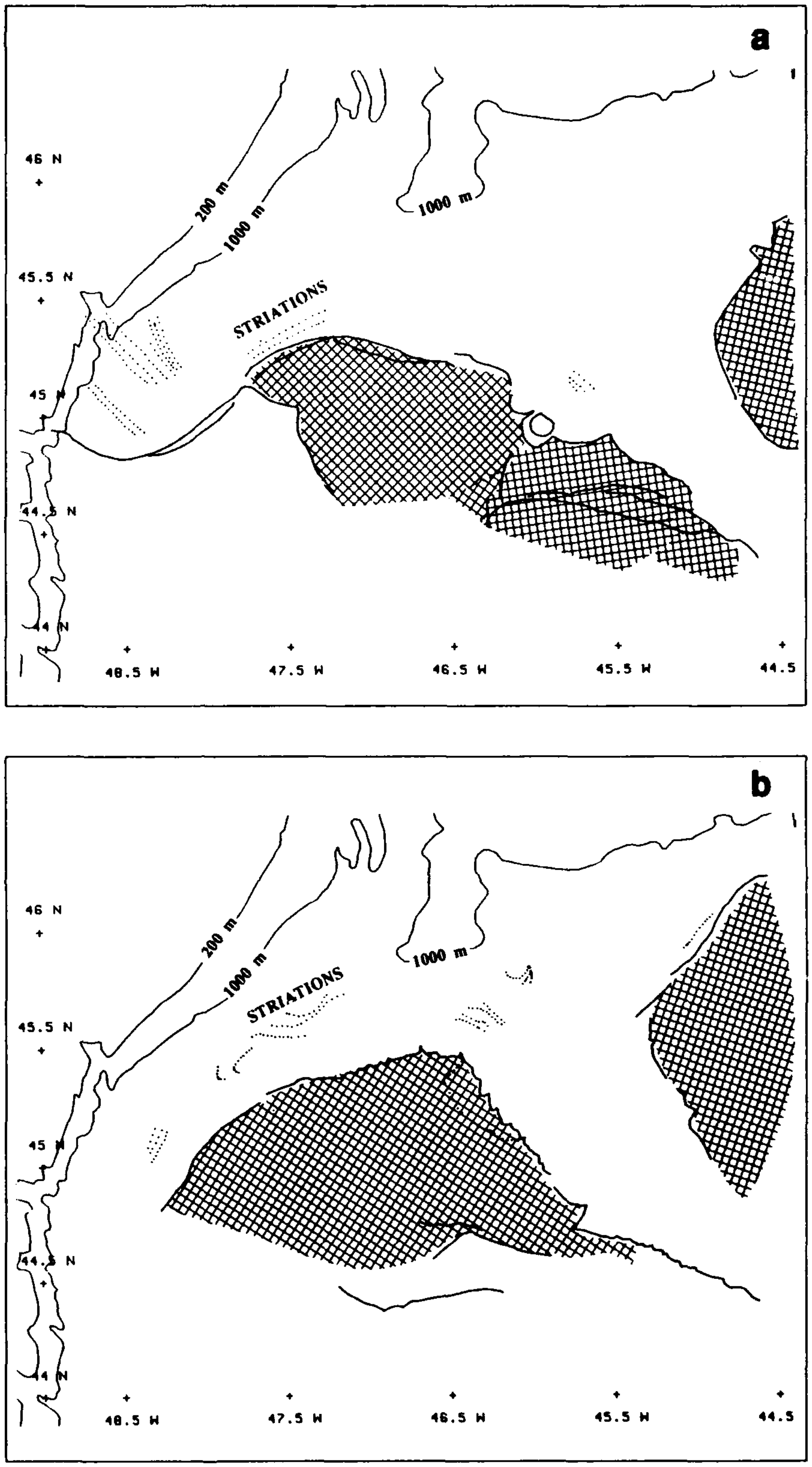


Figure C-6 Photomosaic constructed from the SLAR imagery of 26 April 1986.

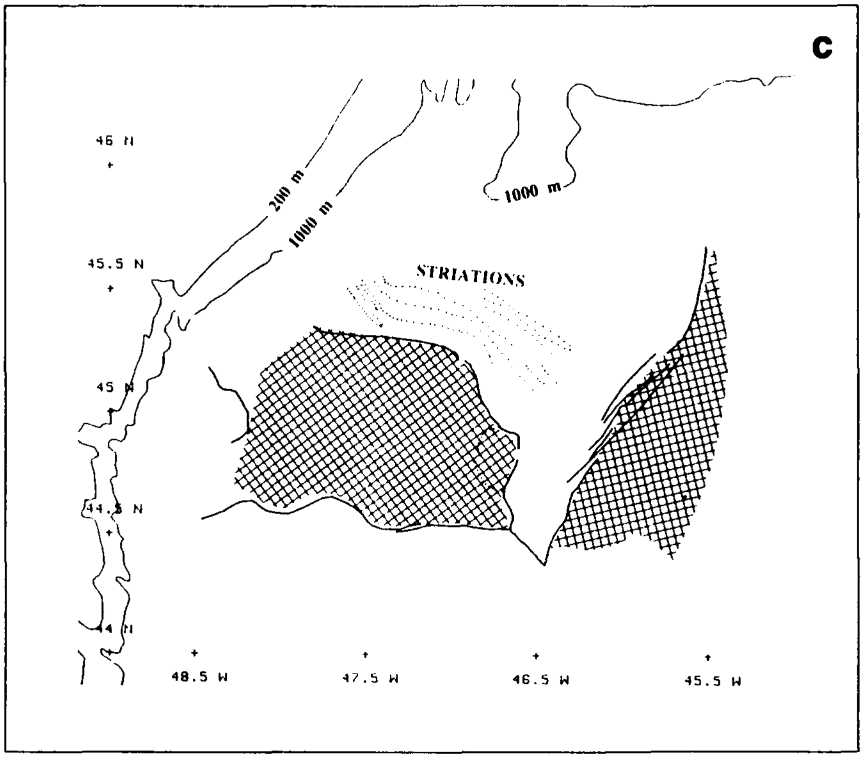
Figure C-7 Digitized fronts depicted in the SLAR imagery for: (a) 26 April; (b) 2 May.



reported curved lines within the eddy. Such lines were never observed in the warm eddy water in the present study but in three of the four surveys (17 May excepted) there was a series of striations (lines) north of the eddy (Figure C-7). They were faint and patchy, but when they were present they were parallel to each other and approximately paralleled the northern boundary of the eddy. SEASAT SAR data also showed similar features, as reported by Cheney(1981) and Fu and Holt(1982), who suggested that the striations were parallel to the flow. There were no direct current observations in either study to confirm this.

Following the evolution of the eddy over the three-week period of observation was difficult for two reasons: first, the inability of the SLAR imagery to provide a closed boundary, and second, the complexity of an eddy interacting with the NAC and trapped against the Grand Bank and the Labrador Current. The location of the northern and eastern boundaries of the eddy was well-defined on both 26 April and 2 May SLAR surveys (Figures C-7a and b); however, in neither survey were the western and southern boundaries well defined. East of the eddy, the boundary of the NAC appeared to have moved about 30 km to the west during the six-day interval between the surveys.

The 9 May SLAR (Figure C-7c) survey provided the most complex and ambiguous images. The northernmost frontal location remained nearly unchanged. This survey provided the first good image of the southern portion of the eddy, as well as the best image of the striations north of the eddy. Unlike the patchy striations observed on the 26 April and 2 May surveys, they were widely distributed north of the eddy. Like the previous image, however, they were roughly parallel to the northern eddy boundary.



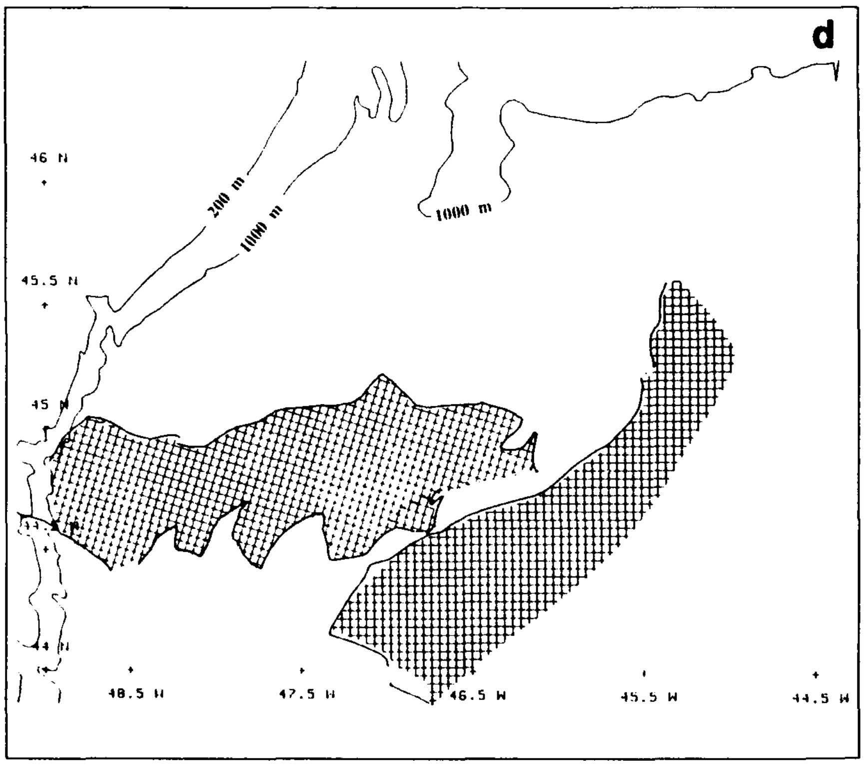


Figure C-7 Digitized fronts depicted in the SLAR imagery for: (c) 9 May; and (d) 17 May.

The 17 May SLAR survey, conducted on the last day of the experiment, provided the most remarkable image (Figure C-7d). It shows an eddy with a complex shape interacting with the NAC.

Along the southern boundary of the eddy is a sawtooth-pattern with a peak-to-peak separation of 35km and a height of 20km. As on the other dates, not all of the boundaries are clearly defined, particularly the western boundary. As a result, it is difficult to estimate the size of the eddy based solely on the SLAR imagery; the best size estimate is 160 by 80 km.

The 17 May imagery gives no hint of striations on the cold water side of the front. This is the only date on which this occurred. May 17 was also the only cloud-free day during the three-week experiment. An AVHRR image from the NOAA 9 satellite, taken 8 hours before the SLAR image, shows an excellent agreement of the frontal boundaries (Figure C-8). In addition, the SLAR boundaries are as sharp as those seen on the IR imagery, unlike the results reported by LaViolette (1983).

Surface-truth

The SLAR imagery depicted a series of boundaries with intricate structure, most of which cannot be resolved by the coarsely spaced oceanographic survey and the tracks from a few buoys. This section deals only with the clearest and largest features.

First Oceanographic Survey

Near surface temperatures from the 26 April - 3 May survey (Figure C-9) supports the interpretation of the dark areas in the 26 April SLAR image as waters of NAC origin. The SLAR-detected front nearly coincides (Figure C-10a) with a sharp thermal front, represented in the figure as the 12°C (chosen as an indication of water of NAC origin) contour of sea

surface (0.5-1.0m) temperature The match is remarkably good in the western portion of the study area, but diminishes somewhat toward the east as the time separation between the imagery and hydrography approaches 4 to 5 days. Some of the mismatch is due to the coarse hydrographic grid, but most is due to the fact that the fronts were moving over the period of the hydrographic survey. A comparison of the 12°C surface temperature and the 2 May SLAR imagery (Figure C-10b) shows an excellent match in the eastern part of the study area. The easternmost hydrographic survey line was completed on 3 May.

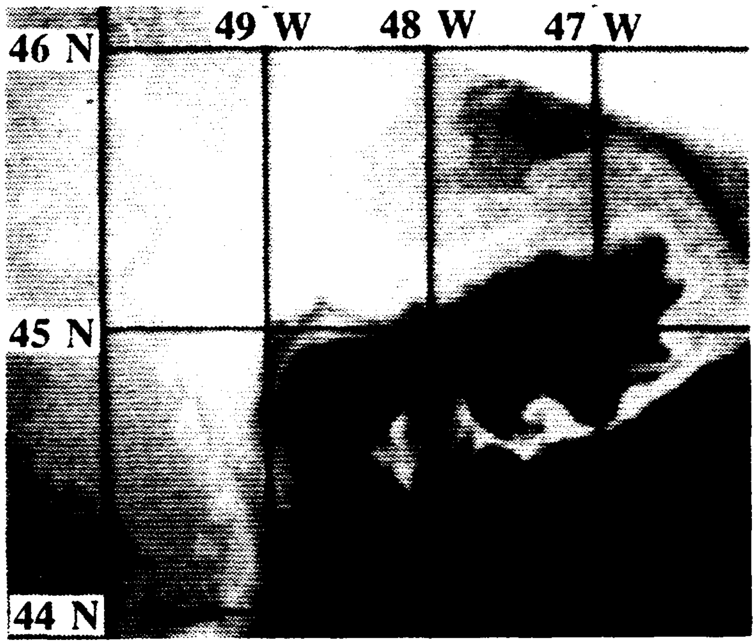


Figure C-8 Infrared Image from the Advanced Very High Resolution Radiometer aboard NOAA 9 on 17 May.

The water-mass characteristics across the SLAR-detected front are best illustrated by Figure C-11, a temperature and salinity profile along section AC shown in Figure C-10a. It shows two sharp thermal fronts that coincide with those shown on the 26 April SLAR imagery. In the north, a surface temperature difference of 11°C exists between hydrographic stations on either side of the front, while in the south (C), the difference was 8°C. Between the two fronts is water of NAC origin. The isotherms dome sharply downward, with the 8°C isotherm reaching 320db. In the northern portion of the section (along AB) cold, low salinity water indicates the presence of Labrador Current water flowing eastward immediately to the north of the northern front. In this transect the core of the cold water was at 50 dbar, with a minimum temperature of -0.9°C; at this depth the salinity was 33.1 ppt. The cold-water core was seen at all 10 of the north-south sections of the first-phase hydrography. Typically, the lowest temperatures were found at 40m to 50m.

Figure C-12 shows the horizontal distribution of temperature at 58m, in which the 0°C contour is used to define the location of the core of the Labrador Current water. The 58m depth is chosen because it is the depth of the drogue center of the drifting buoys. Also plotted is the trajectory of a drifting buoy (ID 4542) deployed from an aircraft in Flemish Pass on 19 April. It arrived in the study area on 25 April, the day before the first SLAR survey and the beginning of the first hydrographic survey. The buoy track follows the 0°C contour remarkably well, recognizing that over the six-day period the front changed shape somewhat. The average buoy speed from A to B was 67 cm/s. Referring back to Figure C-11, the buoy passed almost exactly through station 20 and, with the center of the drogue at 58m, it was moving with the 0°C water. When the buoy reached its easternmost extent, it made a sharp cyclonic bend (radius = 20km) and then moved northwestward and eventually northward at about 50 cm/s before it was recovered on 3 May.

The easternmost hydrographic transect (line CD on Figure C-12) shows a water-property distribution (Figure C-13) that is consistent with the cyclonic bend in the trajectory of buoy 4542. Sub-zero water was found at both stations

65 and 67 but not in between. In both cases, this thin and narrow cold-water core was immediately adjacent to NAC water. The radius of the bend suggested in the hydrography is a function of the north/south station spacing (18 km), but it is approximately the same scale as the buoy track radius. The hydrographic section was taken three days after the buoy passed through the area. This probably explains the fact that the location of the bend in the buoy track and the zero degree water are not coincident.

The orientation of the SLAR-observed striations in the 26 April imagery (Figure C-14) north of the front is coincident with the direction of the buoy motion and the location of the Labrador Current as determined by hydrography.

None of the buoys deployed along the westernmost hydrographic section moved through the survey area, so their trajectories (Figure C-14) are of limited use. Buoy 4536 was deployed with its drogue in Labrador Current water about 4 km from a location that buoy 4542 moved through 48 hours earlier; however, while buoy 4542 moved rapidly to the east north of the eddy, 4536 moved sluggishly (20-30 cm/s) to the southwest , roughly parallel to a front shown on the 26 April imagery. Its subsequent north-westward movement was approximately parallel to the striations recorded by the SLAR four days earlier. There is no supporting hydrography, so it cannot be determined if the subsequent southward buoy motion along the 1000m bottom contour of the

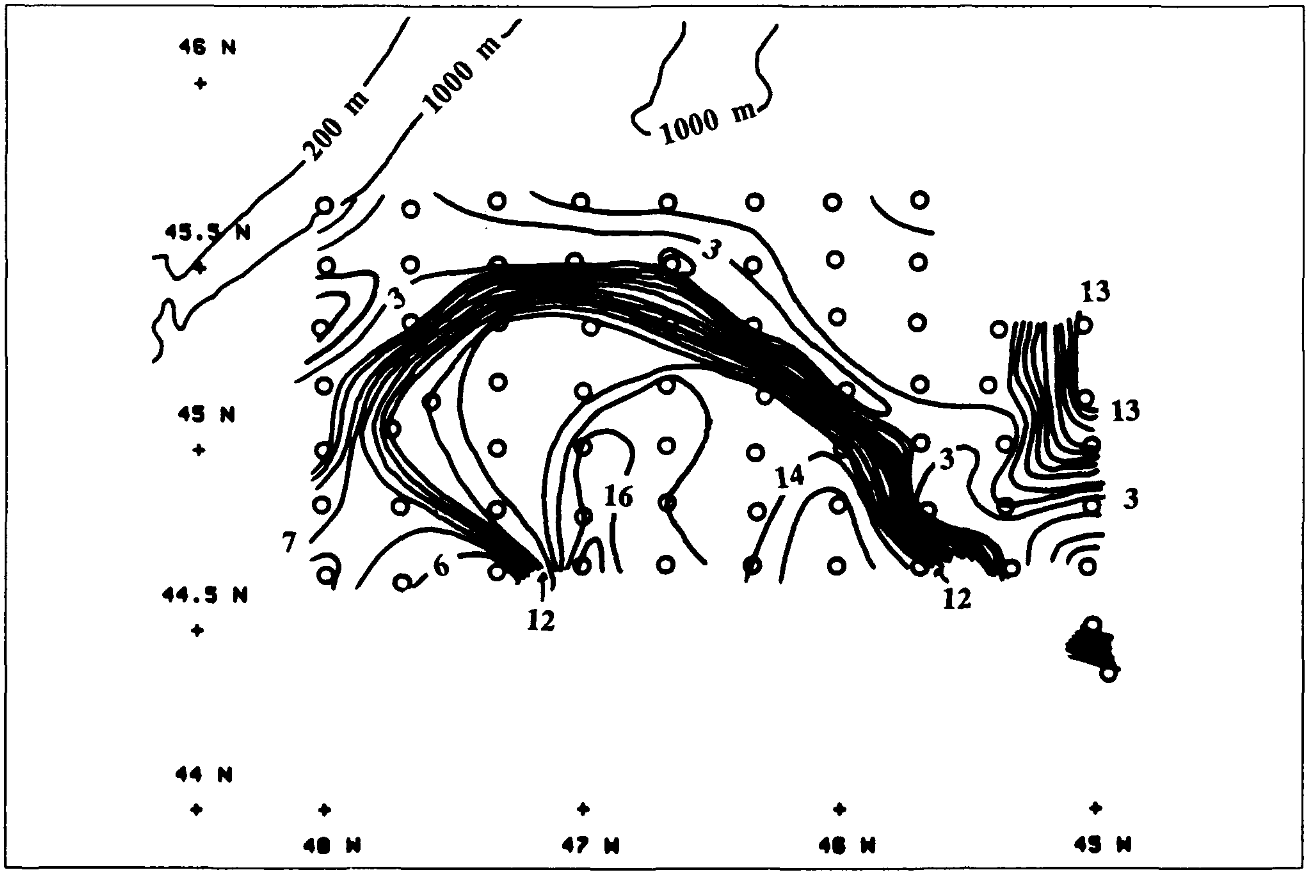
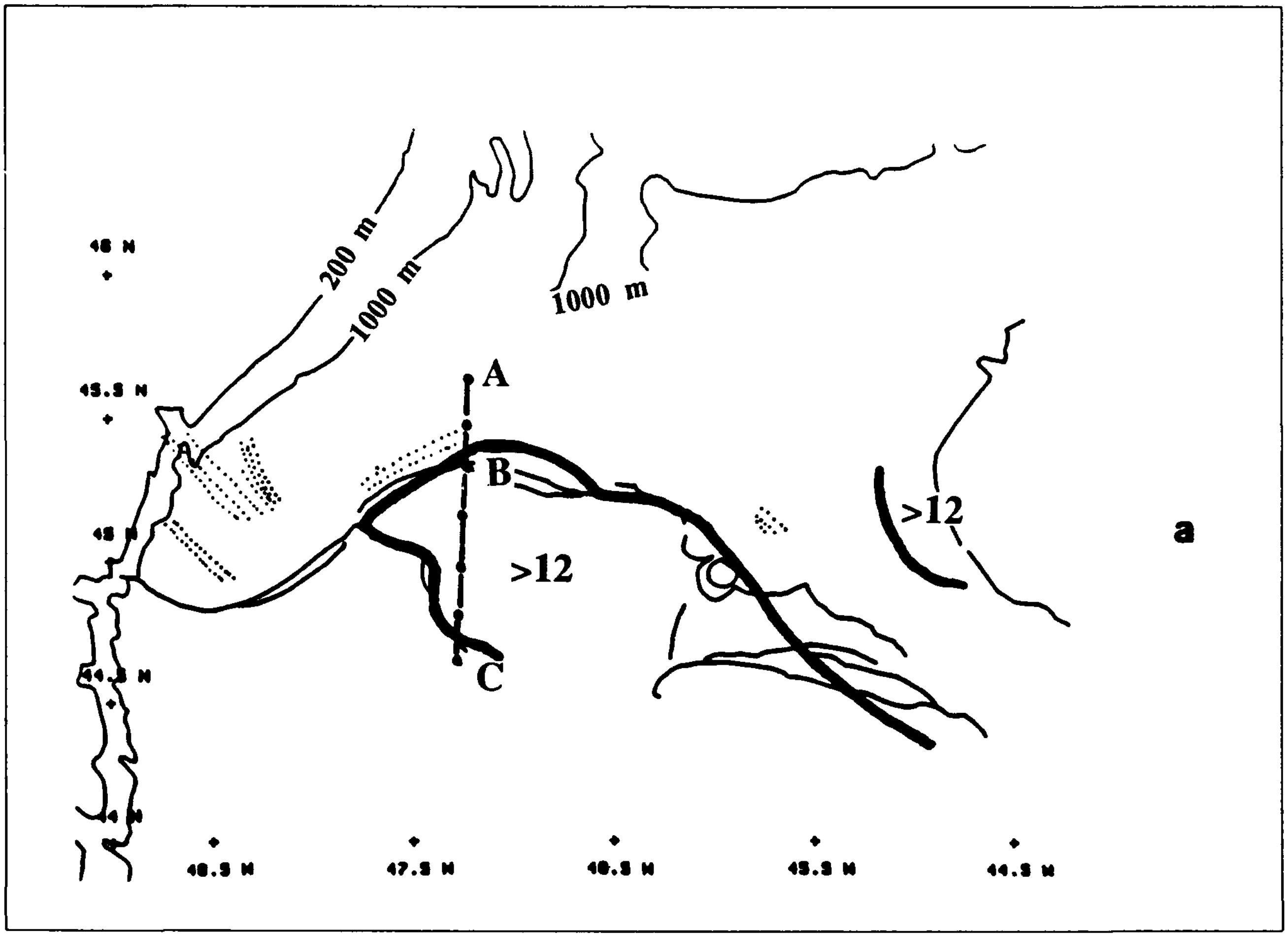


Figure C-9 Sea surface (0.5 - 1.0m) temperature (°C) distribution based on the first phase (27 April — 3 May) hydrography.



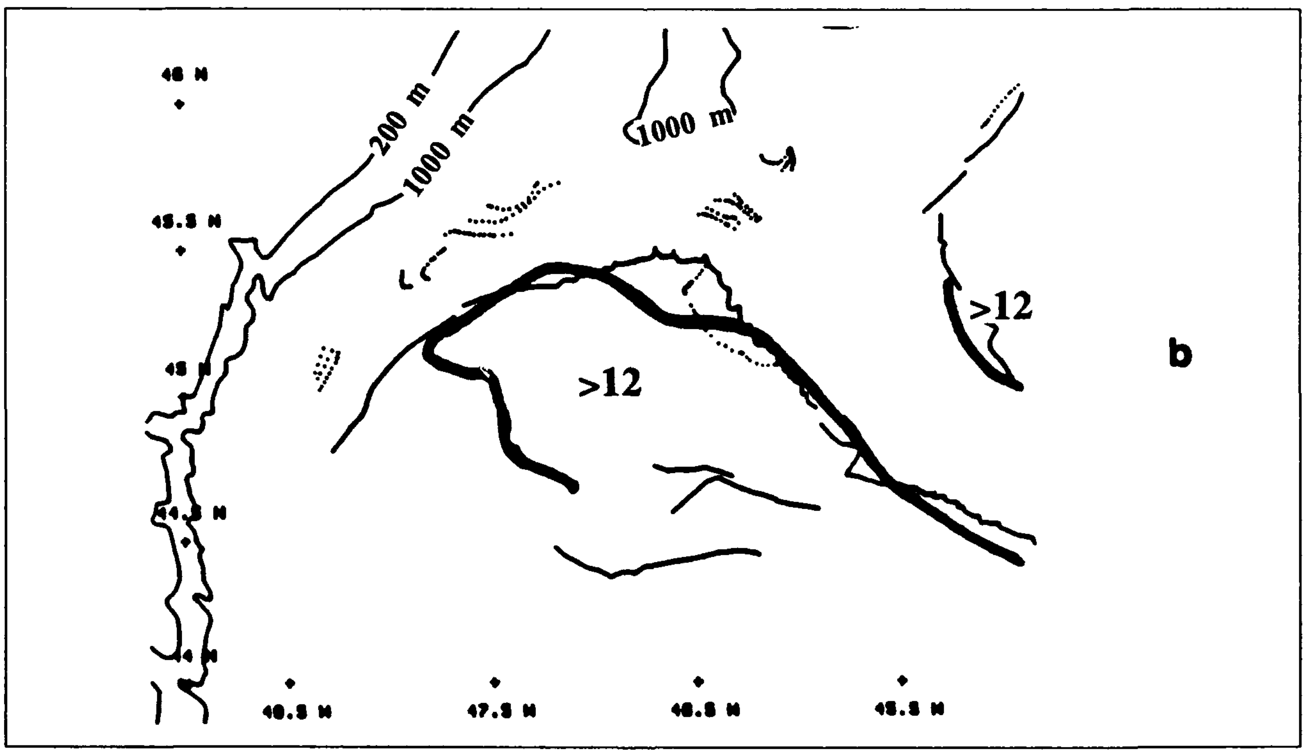


Figure C-10 Comparison between the sea surface temperature (0.5 m - 1m) from the first phase (27 April - 3 May) hydrography and the digitized fronts from SLAR imagery on (a) 26 April and (b) 2 May.

Grand Bank marked the motion of the Labrador Current. The buoy surface temperature reveals no significant thermal structure, with readings mainly in the 2-5°C range. The remaining two buoys exhibited a weak southwestward flow to the southwest of the eddy.

Second Oceanographic Survey

Although abbreviated, the second oceanographic survey, together with the associated buoy tracks, supports the intrepretation of the 9 May imagery as a warm core eddy. The dynamic topography of the 58 dbar surface relative to 1000 dbar (Figure C-15) shows that the SLAR imagery defined all but the western eddy boundary. As before, the area of high radar return was coincident with the warm water of the eddy. A temperature section (Figure C-16) through the eddy reveals downward sloping of the isotherms and the existence of a narrow and shallow core of cold water north of the eddy.

The three buoys released in the eddy (Figure C-17) started an anticyclonic circuit of the eddy. Two were recovered (as duplicating effort); the third remained in the eddy. North of the eddy, buoy 4542 moved rapidly (70 cm/s) eastward within the Labrador Current. On this occasion, however, it turned to the north before reaching 46°W.

Both the dynamic topography and the motion of buoy 4542 in the cold core of the Labrador Current support the interpretation of the striations observed in the SLAR imagery north of the eddy as flow lines oriented parallel to the flow direction.

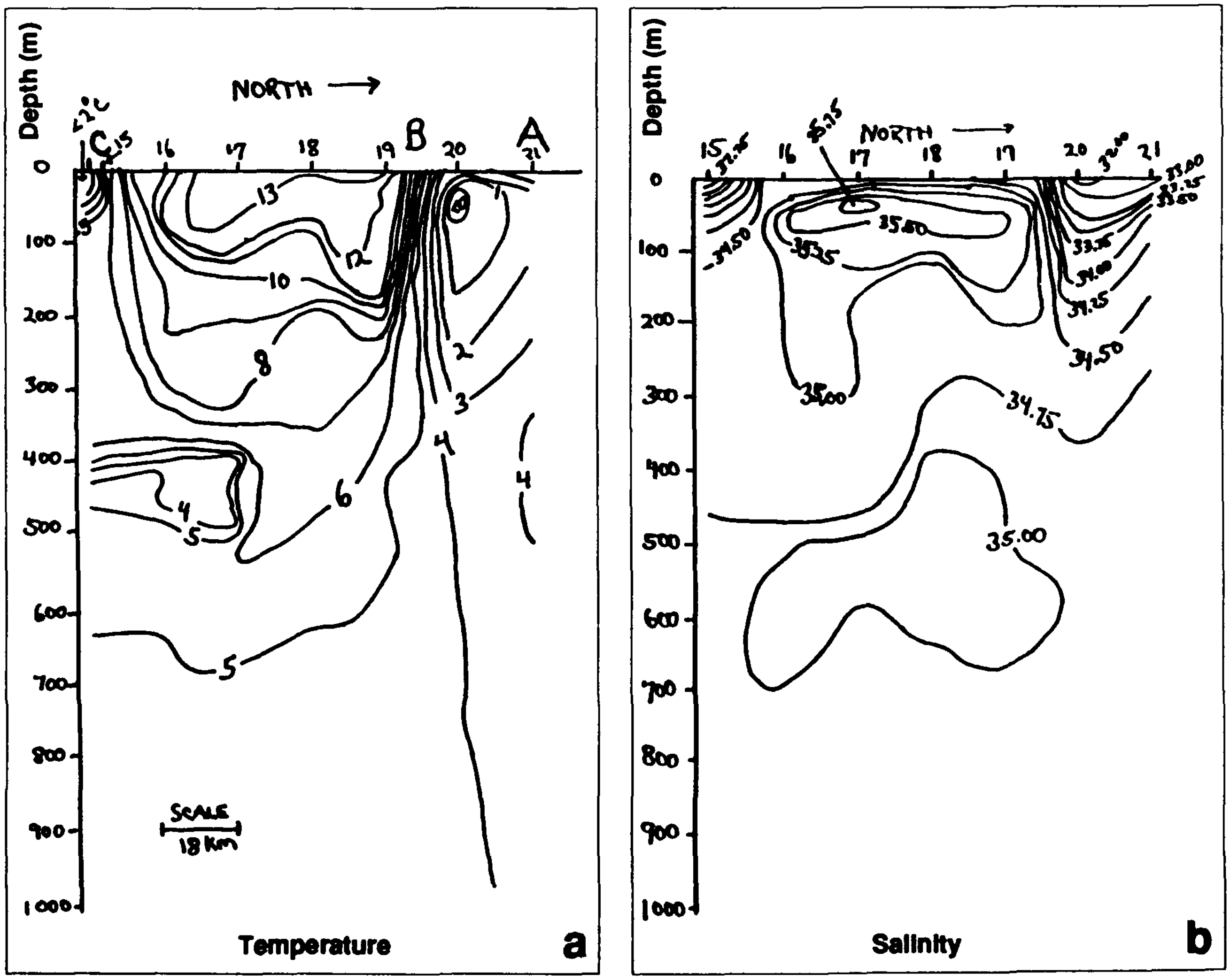
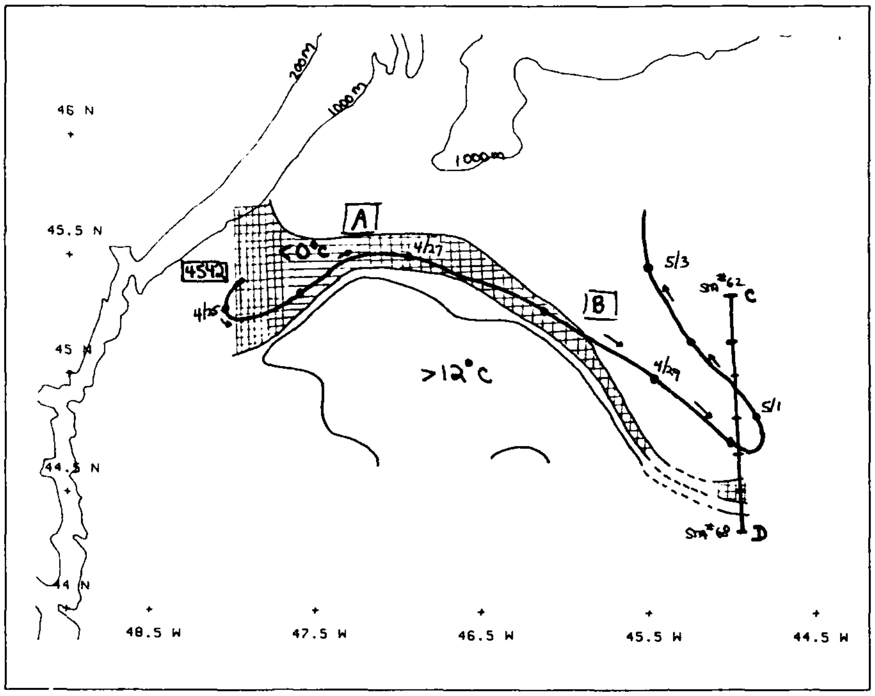


Figure C-11 Temperature (a) and (b) salinity distribution along the north-south hydrographic section marked on Figure C-9. The letters B and C mark the approximate locations of SLAR detected fronts.

Figure C-12 Distribution of temperature at 58 db from the first-phase hydrography (27 April - 3 May) and the track of buoy 4542. The approximate position of the buoy at the beginning of each day is indicated.



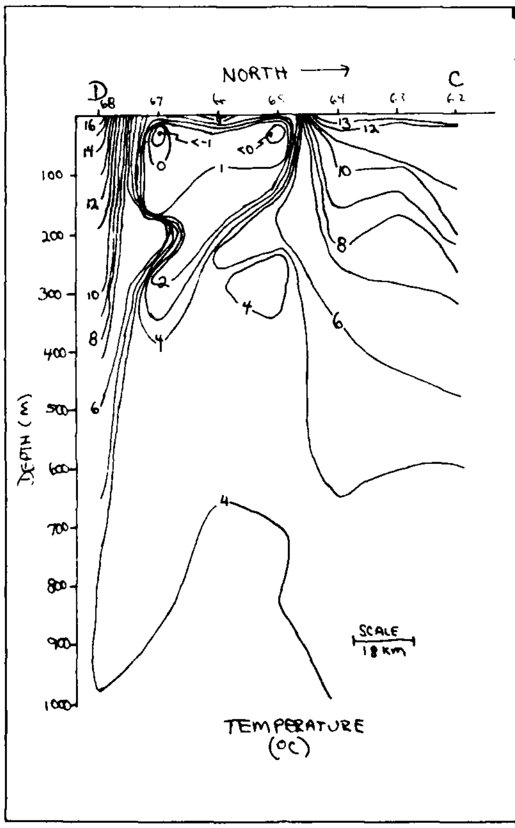


Figure C-13 Temperature distribution along the transect CD drawn on Figure 11.

Subsequent History of the Eddy

The track of the buoy left in the eddy at the conclusion of the hydrography (#4557 on Figure C-18) provides the only data on the eddy after the conclusion of the survey. From 12 May to 9 June, it completed three anticyclonic revolutions of the eddy. Its motion indicates an eddy with a diameter of about 80 km with a southeastward translation of 110 km over the 28-day period, about 4 km/day. During the period the surface temperature was mostly in the 11-13°C range, but there were several intervals when it decreased substantially. For example, for a three-day period (31 May-2 June) the temperature decreased to 5-8°C. This suggests that the buoy was close to the eddy boundary. The drogue was moving persistently within eddy water at 58m, while the hull was at times moving through thin cold features.

On 6 June, IIP attempted a SLAR survey of the region to relocate and map the eddy, but the SLAR failed. On 9 June the buoy apparently departed the eddy. The anticyclonic motion ceased and the surface temperature decreased to 6-8°C for a period of a week.

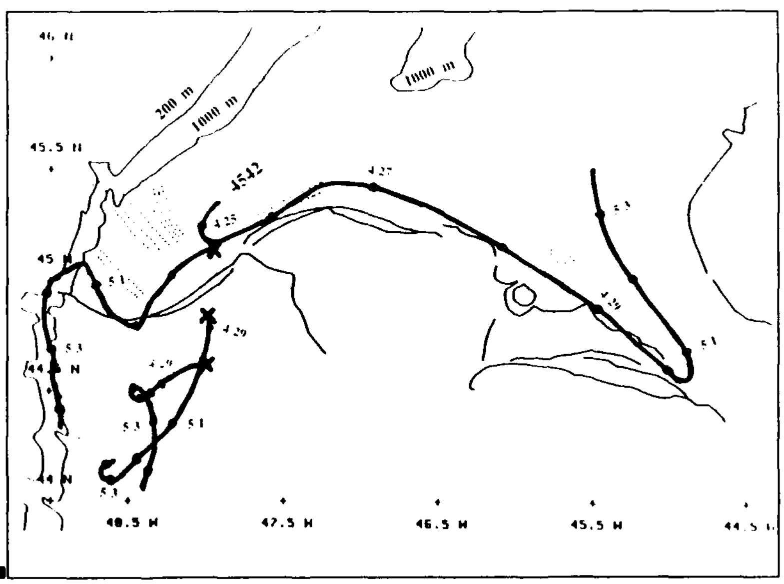


Figure C-14 Comparison of the first-phase buoy tracks and the features from the 26 April SLAR survey.

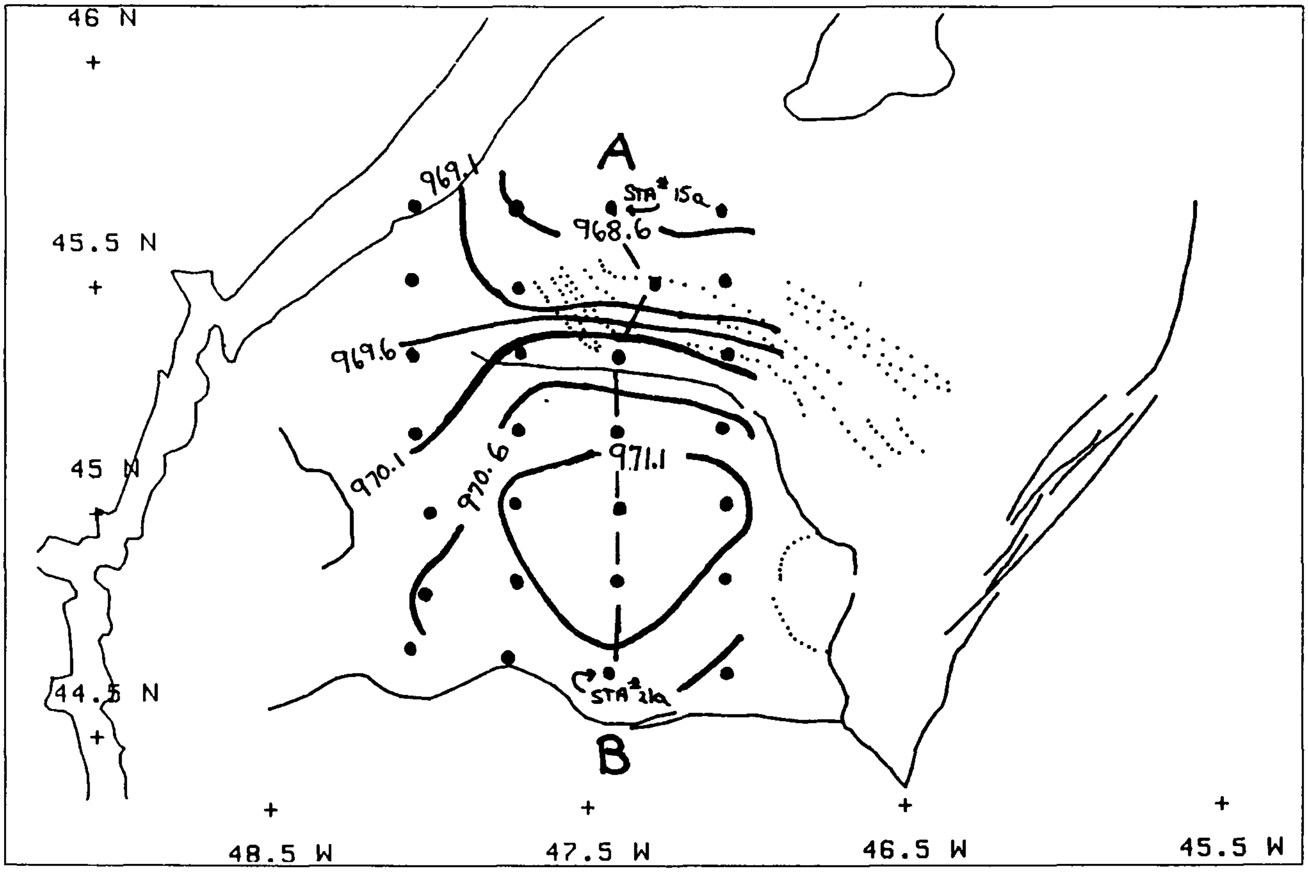


Figure C-15 Comparison between the digitized features from the 9 May SLAR survey and the dynamic topography of the 58 db surface relative to 1000 db (based on second-phase hydrography).

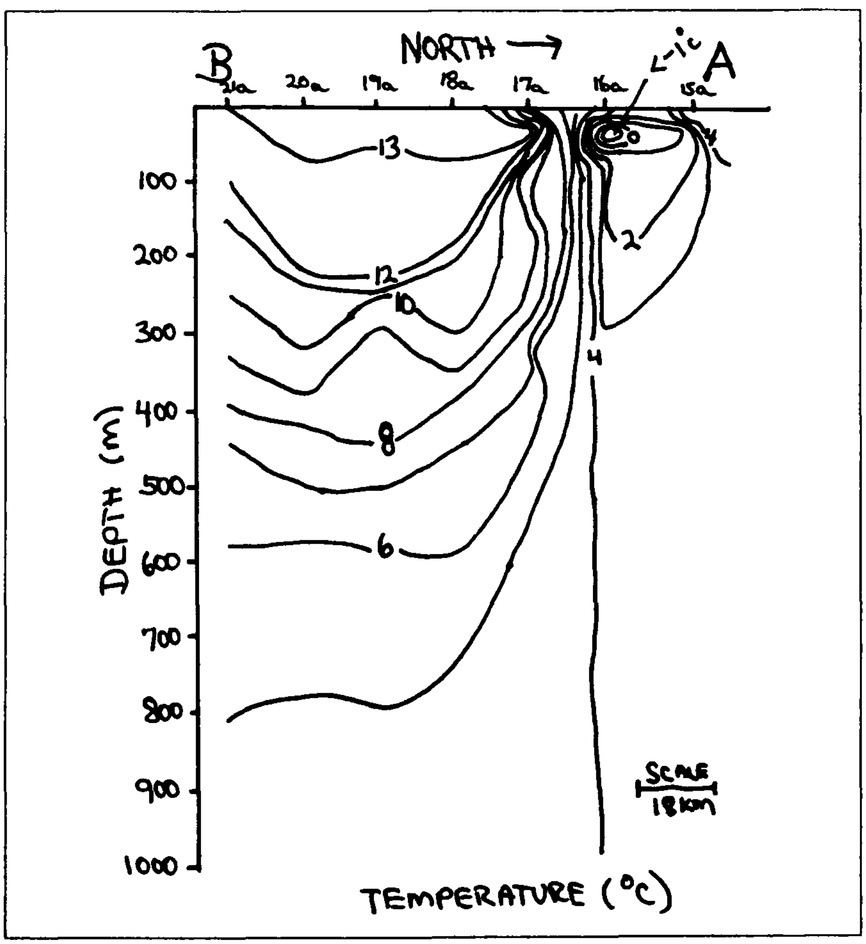


Figure C-16 Second-phase temperature section through the warm core eddy. The location of the section is marked by AB on Figure C-14.

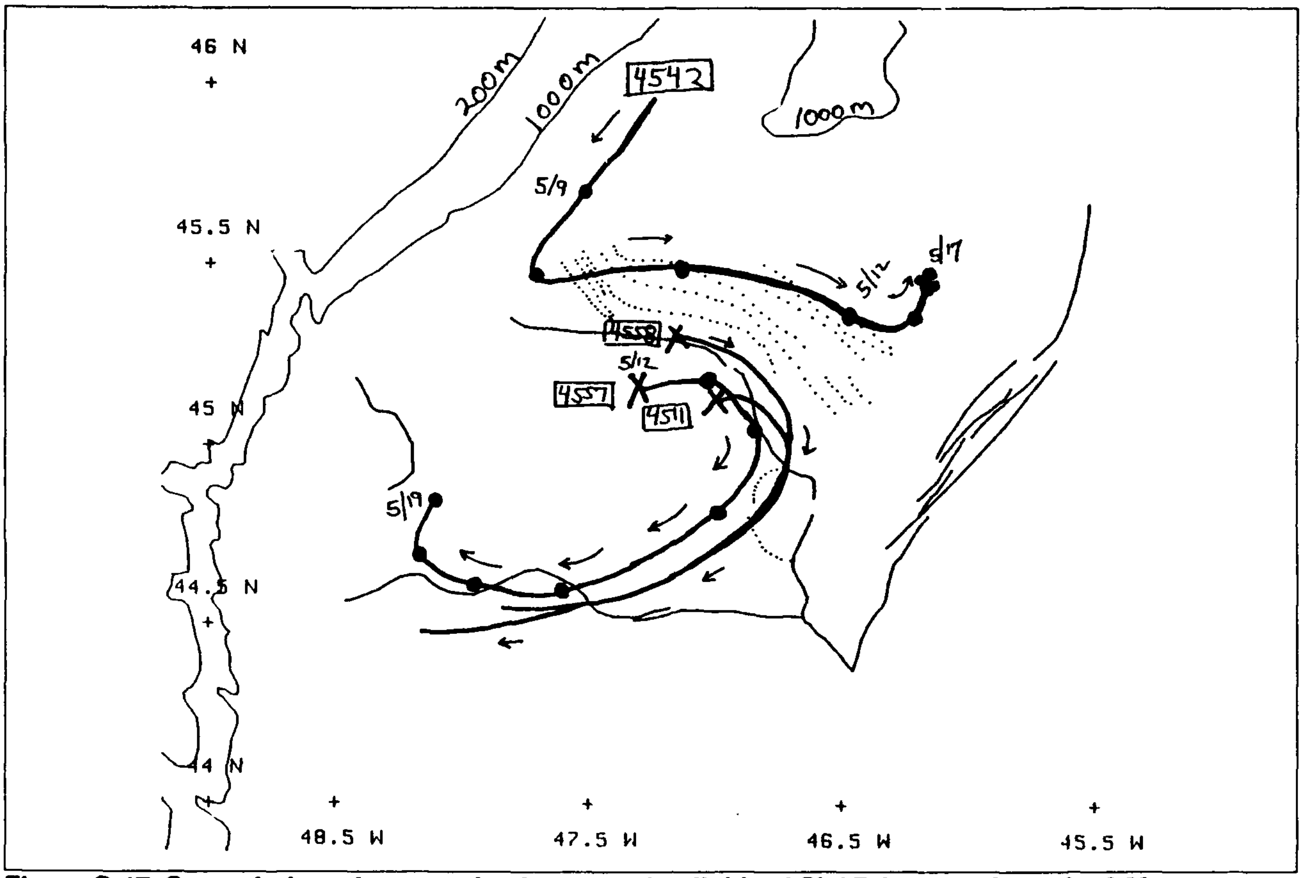


Figure C-17 Second-phase buoy tracks drawn on the digitized SLAR features from the 9 May survey.

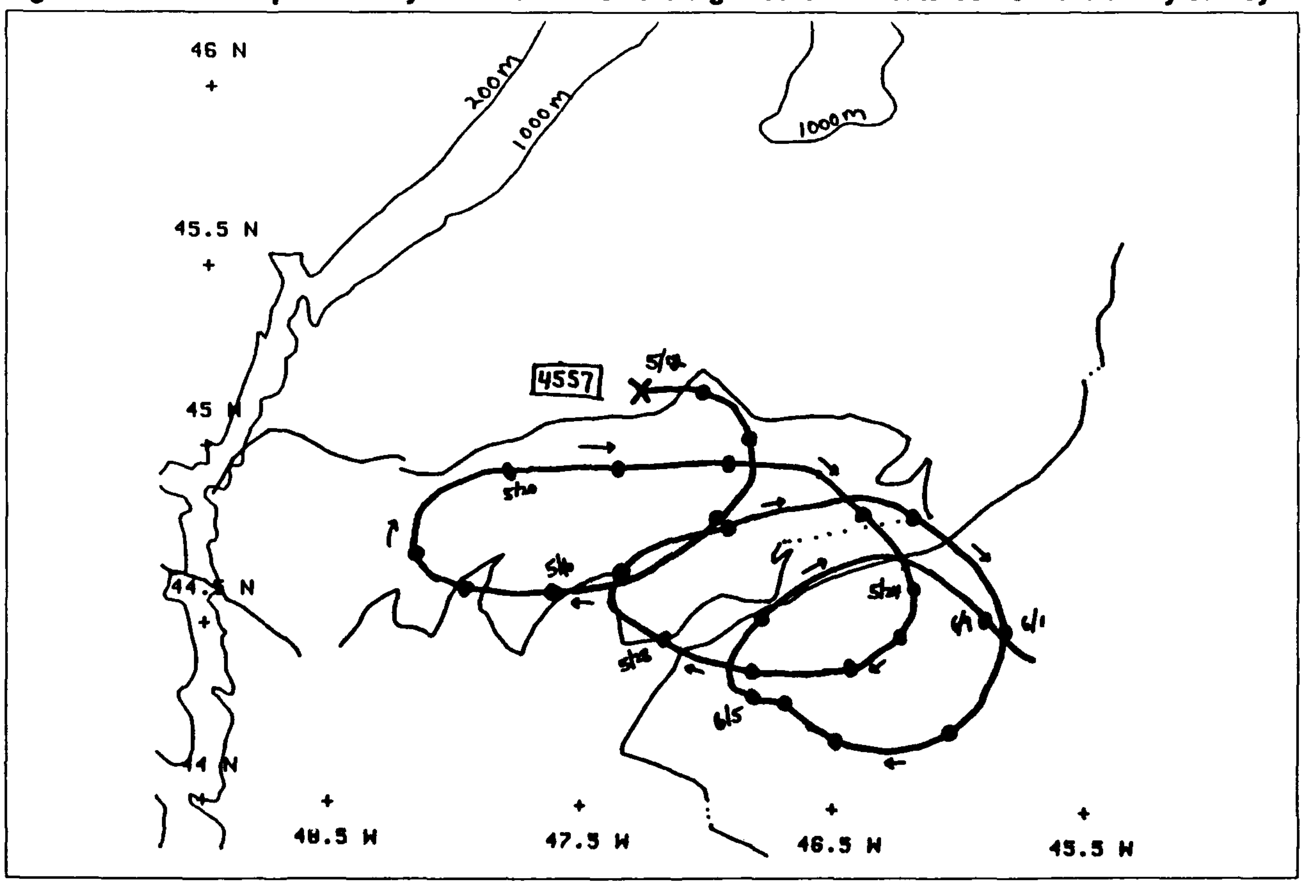


Figure C-18 Trajectory of buoy 4557 plotted on the 17 May SLAR-detected features.

Conclusions

A warm core eddy was found between the LC and NAC east of the Grand Banks of Newfoundland. The observed flow field differed substantially from that suggested by the mean sea-surface topography. During the period of the study, a portion of the Labrador Current left the slope of the Grand Banks north of 45°N and flowed eastward north of a warm core eddy.

The location of a portion of the eddy could be mapped by SLAR. The major cue was the strong signal indicating higher radar return from the warm water within the eddy. However, not all of the boundaries could be located with certainty.

The location and direction of the Labrador Current in the study area could be determined in some of the SLAR imagery using striations as flow lines. These are not reliable indicators, for on most days the striations were faint and patchy. On one day they were absent.

In one case where IR imagery could be compared to concurrently collected SLAR imagery, the match was excellent. The radar-detected fronts were as sharply defined as those in the AVHRR image.

The exact mechanism for the strong radar backscatter in the warm water is uncertain. It is probably due to increased wind stress over the warmer water. Cool air blowing over much warmer water results in an unstable boundary layer, greater wind stress, and a rougher sea surface.

The eddy was never well resolved in either of the hydrographic surveys: that was not the intent of the study. In fact, the best evidence for a closed circulation is the subsequent anticyclonic motion of the buoy left in the eddy after the completion of the hydrography. Exactly when the eddy separated from the NAC cannot be determined from the data. What is clear is the effect that the eddy had on the Labrador Current. The distribution of the unmistakable water mass characteristics of the Labrador Current and the eastward motion of buoy 4542 (on two separate occasions) show that a portion of this current left the slope of the Grand Bank at about 45°N. It moved eastward and then northward in close proximity to the eddy and finally along the boundary of the NAC.

The present study illustrates the importance of research that blends remote sensing with in-situ sampling, with the goal of studying ocean processes. Without the SLAR we could not have located the fronts as easily, nor recognized the spatial and temporal variability of the system. Without the in-situ sampling, the imagery would have been another opportunity for unfounded speculation.

SLAR imagery is difficult to interpret but can be used with other data to gain a better understanding of ocean processes. In addition, SLAR and SAR imagery portray similar features; thus, the more we learn about SLAR now, the better prepared we will be to interpret satellite SAR imagery when it becomes available.

The study results are important to IIP for several reasons. First, they provide a better recognition of the role of eddies in the circulation near the Grand Banks. This study reports a flow pattern that differs dramatically from the mean Labrador Current flow that IIP uses. The observed pattern provides a mechanism for the rapid eastward and even northward motion of icebergs in cold water (minimizing deterioration). There was no apparent cross-front movement. There is no confirmation that the observed flow field caused a major change in iceberg distribution south of Flemish Cap. Indeed, in 1986 only 204 icebergs were reported south of 48°N during the four-month season, giving little opportunity to recognize any iceberg distribution changes from normal. However, a better knowledge of the flow field leads to better iceberg reconnaissance planning. For example, IIP can focus its efforts on an area near the iceberg limit where a large concentration of icebergs is likely.

The IIP SLAR data suffer somewhat from the inability to record digital radar data aboard the aircraft. This is not important for the major features, such as the obvious tonal signal that marked

the eddy. However, for more subtle features like the striations, digital processing would have provided better definition.

The study also illustrates the importance of reliable and good navigation. Each of the major navigation systems used (inertial navigation, LORAN C, and System ARGOS) has different reliability, accuracy and availability. The coarse hydrographic sampling scheme was an accommodation to this problem, and even so, matching three navigational realizations of a physical feature was often difficult. The future offers a solution in the Global Positioning System, but for the next few years the problem will remain.

The use of aircraft-borne SLAR, and eventually satellite-borne SAR, in determining ocean circulation near the Grand Banks holds great promise for improving IIP operations. However, the work in interpreting radar imagery of the ocean surface has only started. Experiments such as that described here must be repeated several times with a broad range of ocean features. Ultimately, the combination of active microwave imagery and air-deployed buoys will permit IIP to gather the required near real-time data.

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References

Anderson, I., 1983. Oceanographic Conditions on the Grand Banks During the 1983 International Ice Patrol Season. Appendix B to Report of the International IcePatrol in the North Atlantic. Bulletin No. 69, CG-188-38, U.S. Coast Guard, Washington, D.C. 20593, 73pp.

Anderson, I.,1984. Oceanographic Conditions on the Grand Banks During the 1984 International Ice Patrol Season. Appendix B to Report of the International IcePatrol in the North Atlantic. Bulletin No. 70, CG-188-39, U.S. Coast Guard, Washington, D.C. 20593, 74 pp.

Bessis, J. L., 1981. Operational Data Collection and Platform Location by Satellite. Remote Sensing of Environment, Vol II: p 93-111.

Cheney, R. E., 1981. A Search for Cold Water Rings, in Spaceborne Synthetic Aperture Radar for Oceanography. The Johns Hopkins Oceanographic Studies,ed. by R.C. Beal. The Johns Hopkins University Press, Baltimore, MD, p. 161-170.

Fofonoff, N. P., 1985. Physical Properties of Seawater: A New Salinity Scale and Equation of State for Seawater. Journal of Geophysical Research, Vol 90(C2): p. 3332 - 3342.

Fu,L. and B. Holt, 1982. SEASAT Views Oceans and Sea Ice with Synthetic Aperture Radar. Publication 81-120, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, 200pp.

Hayes,R.M., 1981. Detection of the Gulf Stream, in Spaceborne Synthetic Aperture Radar for Oceanography. The Johns Hopkins Oceanographic Studies, ed. by R.C. Beal. The Johns Hopkins University Press, Baltimore, MD, p. 146-160.

LaVoilette, P. E., 1983. The Grand Banks Experiment: A Satellite/Aircraft/Ship Experiment to Explore the Ability of Specialized Radars to Define Ocean Fronts. Report 49. Naval Ocean Research and Development Activity, NSTL Station, MS 39529, 126 pp.

Lichy, D. E., M. G. Mattie, and L. J. Mancini, 1981. Tracking of a Warm Core Eddy, in Spaceborne Synthetic Aperture Radar for Oceanography. The Johns Hopkins Oceanographic Studies, ed. by R.C. Beal. The Johns Hopkins University Press, Baltimore, MD, p. 171-182.

Murray, J. J., 1979. Oceanographic Conditions. Appendix B to Report of the International Ice Patrol in the North Atlantic. Bulletin No. 65, CG-188-34, U.S. Coast Guard, Washington, D.C. 20593, 31 pp.

Robinson, I. S., 1985. Satellite Oceanography: An Introduction for Oceanographers and Remote-Sensing Scientists. West Sussex, England: Horwood Limited. 455pp.

Scobie, R. W.and R. H. Schultz, 1976. Oceanography of the Grand Banks Region of Newfoundland March 1971-December 1972. Oceanographic Report No. CG-373-70, U.S. Coast Guard, Washington,D.C. 20593, 298 pp.

Soule, F. M., 1964. The Normal Dynamic Topography of the Labrador Current and its Environs in the Vicinity of the Grand Banks of Newfoundland During Iceberg Season. Report 64-36, Woods Hole Oceanographic Institution, Woods Hole MA, 9 pp.

Vesecky, J.F. and R. H. Stewart, 1982. The Observation of Ocean Surface Phenomena Using Imagery from the SEASAT Synthetic Aperture Radar: An Assessment. Journal of Geophysical Research, 87(C5):3397-3430.

Williams, F. J., 1985. Investigation of Eddy Population and motion in the Southern International Ice Patrol Operations Area (40-47N by 40-55 W). M.S. Thesis. Old Dominion University, 69 pp.

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